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ABSTRACT

This book provides clear-cut insights along with practical suggestions on how to develop teaching competencies and strategies and implement inquiry as called for by the national standards. The chapters in this book take the reader through constructing an understanding of inquiry and the characteristics of an inquiry-based classroom, then address what constitutes an inquiry investigation and the teaching strategies that enhance inquiry-based learning. Chapter 1, "What Is Inquiry?" explores the meaning of inquiry through a constructivist approach. Chapter 2, "Learning through Inquiry", follows a 4th grade class through a unit of study characterized by student-generated questions. Chapter 3, "What Is Constructivism?" lays the foundation for constructivist learning strategies and shows how constructivism complements inquiry-based learning. In chapter 4, "Designing Inquiry-Based Classrooms," traditional and inquiry-based classrooms are compared. In chapter 5, "Integrating Inquiry-Based Classrooms," inquiry investigations are compared with other hands-on science activities through a grid that divides instructional strategies into demonstrations, activities, teacher-initiated inquiries, and student-initiated inquiries. Chapter 6, "Why the Scientific Method is Important," compares inquiry with the scientific method and scientific problem solving whereas chapter 7 introduces The Learning Cycle, a five-step approach to designing lessons that facilitate inquiry. Chapter 8, "Skills and Knowledge of Inquiry-Based Teachers", presents a rubric for assessing and monitoring the four stages of development in becoming an inquiry-based teacher. Chapter 9, "Using Questioning Skills in Inquiry," presents questioning strategies that enable inquiry-based learning. In chapter 10, "Inquiry-Based Teachers Describe the Process," a beginning elementary school teacher describes her journey into inquiry and a college professor shares her insights about using inquiry. Both describe their experiences including the joys, the challenges, and the rewards of teaching through inquiry. Resource A, "Inquiry Resources for Teachers," provides printed and online resources for further reading and reference. It is essential that those interested in inquiry-based instruction go beyond the initial stages of understanding inquiry to a level at which they can articulate personal philosophies grounded in research and literature. Linking theory and practice requires additional reading and discourse. (Contains 65 references.) (ASK)

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Inquire Within

DOUGLAS LLEWELLYN

Inquire Within

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Contents

Preface ix
Why Inquiry? Why Now? ix
Who Should Read This Book? x
Contents xi
Acknowledgments xii

About the Author xv

1. What Is Inquiry? 1
What the Experts Say 3
What the Exploratorium Means by Inquiry 5
What the *National Science Education Standards* Say About Inquiry 6
What the American Association for the Advancement of Science Says About Inquiry 6
Myths About Inquiry-Based Learning 7
Inquiry as a Thinking Skill 10
"Inquiring With Fruit" 11
The Inquiry Cycle 13
A Definition of Inquiry 16

2. Learning Through Inquiry 17
Day 1: Exploring Ice Hands 17
Day 2: Planning an Investigation 21
Day 3: Carrying Out the Plan 21
Day 4: Organizing the Data 24
Day 5: Communicating the Results 24
Conclusion 27

3. What Is Constructivism? 29
Developing a Mind-Set for Inquiry 29
What Is Constructivism? 29
Constructivist Learning Model 30
The Conceptual Change Model 31
Can I Change My Mind? 32
Misconceptions: What You Know May Not Be So 32
Where Do Misconceptions Come From? 34
Comparing the Earth and the Moon 36
How Far Is the Moon? 37
Why Teach to Misconceptions? 38
Uncovering Misconceptions in Science 38

Historical Development of Constructivism 39
Constructivism Today 44
Back to the Ice Hands 45
Constructivist Classrooms 46
How Scientists Do Science 46
How Children Learn 49
The Child as a Scientist 51
Teaching Science Through Inquiry 51

4. **Designing Inquiry-Based Classrooms** 53
Traditional and Inquiry-Centered Classrooms 53
Building a Definition for an Inquiry-Centered Classroom 54
Students in Inquiry-Centered Classrooms 54
Students Acting as Researchers 56
Students Working in Groups 57
Students Using Higher-Level Thinking Skills 58
Students Showing Interest in Science 58
Teachers in an Inquiry-Centered Classroom 59
An Inquiry-Centered Classroom 60

5. **Integrating Inquiry-Based Activities** 63
Promoting Student Inquiries 63
Invitation to Inquiry 64
Demonstrations 65
Discrepant Events 65
"Happy and Unhappy Balls" 66
Activities 66
Teacher-Initiated Inquiries 68
Student-Initiated Inquiries 69
Guiding Students Into Inquiry 69
Modifying an Activity Into an Inquiry Investigation 76
Planning for Inquiry 78

6. **Why the Scientific Method Is Important** 79
The Scientific Method 79
"Exploring Momentum With Ramps and Balls" 82
A Word of Caution 85
Scientific Problem Solving 85
Scientific Problem Solving Versus Inquiry 86
A Model for Scientific Problem Solving 87
Why We Do Scientific Problem-Solving Activities 89

7. **What Is the Learning Cycle?** 90
What Is the Learning Cycle? 91
"Mealworms to Go": A Student-Initiated Inquiry 93
Authentic Assessments 99

Portfolios 99
Rubrics 100
Monitoring Charts 101
Concept Maps 101
Self-Evaluations 101
Celebrating Learning 103
Summary of an Inquiry Unit 103

8. Skills and Knowledge of Inquiry-Based Teachers 107
Inquiry 101 107
It's Electric! 108
Your First Try at Inquiry 108
Commitment 109
An Inquiry Rubric 109
An Inquiry Self-Assessment Survey 110
Evaluating Your Responses 114
Bugs-o-Copters 116
How Many "What If" and "I Wonder" Questions Can You Think Of? 117
Becoming an Inquiry Teacher 118

9. Using Questioning Skills in Inquiry 127
Questions: The Language of Inquiry 127
Why You Can't Investigate a "Why" Question 128
Classroom Questions 128
Wait-Time 131
Answering Questions and Questioning Answers 131
Types of Questions 134
Interaction of Questioning 135

10. Inquiry-Based Teachers Describe the Process 138
Danielle Dzinbal 138
Lucia Falsetti Guarino, PhD 141
Summary 146

Resource A: Inquiry Resources for Teachers 147
Resource B: Inquiry Self-Assessment Response Grids 158
Resource C: Inquiry Self-Assessment Summary Matrix 162
Resource D: Diagrams for Short-Eared and Long-Eared Bugs-o-Copters 163
Resource E: How to Make a Cartesian Driver 165
References 166
Author Index 169
Subject Index 171

Preface

Inquiry into authentic questions generated from student experiences is the central strategy for teaching science.

—National Research Council (1996)

WHY INQUIRY? WHY NOW?

Recently, two national organizations, the American Association for the Advancement of Science (AAAS; 1993) and the National Research Council (NRC; 1996), have identified content and performance standards necessary for the United States to develop a scientifically literate society and to gain an international reputation in science. Both organizations have identified specifically what students need to know and be able to do at grade levels kindergarten through 12. They have addressed the content of science as well as the way science should be taught.

A common thread to both organizational recommendations has been the citation of inquiry-based instruction as a central strategy for teaching science. Moreover, inquiry has been identified as the preferred method of instruction within the teaching and professional development sections of the *National Science Education Standards* (*NSES*) (NRC, 1996). Therefore, the national standards are encouraging science teachers to plan inquiry-based science programs for their students and develop communities of learners who reflect the intellectual attitudes and social values conducive to science inquiry. In addition, the professional development of science teachers requires them to learn science content through the perspectives and methods of inquiry (NRC, 1996).

In January 1998, the National Science Teachers Association (NSTA) adopted its position statement, *The National Science Education Standards: A Vision for the Improvement of Science Teaching and Learning*. In that statement, the NSTA strongly supports the *NSES* by asserting the following:

> Teachers regardless of grade level, should promote inquiry-based instruction and provide classroom environments and experiences that facilitate students' learning in science . . . professional development activities should involve teachers in the learning of science and pedagogy through inquiry . . . [and] inquiry should be viewed as an instructional outcome (knowing and doing) for students to achieve in addition to its use as a pedagogical approach. (pp. 32-33)

In other words, both elementary and secondary school science teachers must, following the standards, develop teaching competencies and strategies for providing inquiry-based investigations for students.

Writing for the "Invited Paper" column in *The Science Teacher*, Yager (1997) said,

> Inquiry has become a sacred word in science education circles. Everyone recognizes it as important, accepts it, and proclaims its centrality to science teaching. Little has been done, however, to practice inquiry teaching at any level, especially in colleges and universities. (p. 8)

Although once again, we hear the call for reform in science education, no real reform will occur until educators begin to implement the national standards in classrooms across this country. This book focuses on raising a teacher's capacity to teach science through an inquiry-based process, implementing inquiry as stated by the national standards.

WHO SHOULD READ THIS BOOK?

You may be interested in this book for several reasons. As an elementary or secondary school science teacher, you might feel you are already a good hands-on teacher but you want to take the next step in becoming an inquiry-based teacher. You may have read about inquiry in your college courses in preparation for becoming a science teacher. Maybe you have read articles about inquiry in *Science and Children, Science Scope,* or *The Science Teacher* and wondered, "Am I an inquiry teacher?" Or maybe you already feel you are an inquiry-based teacher. This book will enable you to articulate your understanding of becoming an inquiry teacher and enable you to describe, theoretically and practically, why this way of teaching fits your identity as a science teacher.

As a science department head, principal, or curriculum supervisor interested in improving science literacy in your school district, you will be provided with suggestions to facilitate professional development in inquiry-based instruction. As a college professor concerned about providing students with appropriate instruction in the methodology of inquiry, you will be provided with an introduction to inquiry-based teaching.

Teacher competency in inquiry-based instruction is not developed simply by providing inquiry lessons to students or giving them opportunities to do inquiry The process is much more involved than that. It is a journey that starts with developing an inquiry-based mind-set and reflecting on our present beliefs, practices, and understandings. You may begin your journey by accepting an invitation to *inquire within* the pages of this book.

At the completion of this journey, you can expect to have gained enough confidence in inquiry-based instruction to invite your students to begin their own journeys, perhaps beginning with that same invitation hanging on the door of the classroom: Inquire Within. The sign would communicate to students that they are about to enter a *world of inquiry,* where they will be invited to engage in meaningful investigations.

The title of this book has personal meaning, starting with the question "How can we expect our students to engage in inquiry-based activities if we, as teachers, do not have a sufficient understanding of inquiry ourselves?" Often, we view inquiry as a set of activities that students are asked to do. During a recent teacher workshop, I asked the participating teachers to define inquiry. They responded by naming types of activities presented to students and describing what students are expected to do. Their responses included descriptions that characterized student learning, such as "students are active learners," "students are asking questions and solving their own problems," "there is lots of activity about" or "students are encouraged to think for themselves." Although we might agree with these responses, before we can expect our students to inquire, we must raise our own capacity to understand and do inquiry ourselves. The title's metaphor exists to stimulate our need to develop good inquiring minds and strategies and further invites us to begin our journey by inquiring within ourselves.

CONTENTS

The chapters in this book will take you through constructing an understanding of inquiry and the characteristics of an inquiry-based classroom. Later, we address what constitutes an inquiry investigation and the teaching strategies that enhance inquiry-based learning.

Chapter 1, "What Is Inquiry?," explores the meaning of inquiry through a constructivist approach. After writing your own definition of inquiry, you will use several statements from the *National Science Education Standards, Benchmarks for Science Literacy,* and the Exploratorium (a hands-on science museum in San Francisco) to verify and modify your understanding of inquiry. Later in the chapter, several myths of inquiry-based learning are uncovered to further an understanding of what inquiry is and what it is not.

Chapter 2, "Learning Through Inquiry," follows a fourth-grade class through a unit of study characterized by student-generated questions.

Chapter 3, "What Is Constructivism?," lays the foundation for constructivist learning strategies and shows how constructivism complements inquiry-based learning. Although constructivism has gained much support among science educators in the past 10 years, it is not a new idea. Its theoretical foundations began with the work of cognitive psychologists such as John Dewey, Jean Piaget, and David Ausubel. In Chapter 3, we also address children's naive conceptions or misconceptions in science and how they influence the learning process. We examine the way children learn science through a constructivist approach and compare it with the way scientists do science. Emphasis is placed on how science process skills such as observing, inferring, and model building enable students to construct knowledge and make meaning of science.

In Chapter 4, "Designing Inquiry-Based Classrooms," traditional and inquiry-based classrooms are compared. By looking at the differences in students, teachers, and classroom environments, you will further your understanding of inquiry-based classrooms.

In Chapter 5, "Integrating Inquiry-Based Classrooms," inquiry investigations are compared with other hands-on science activities through a grid that divides instructional strategies into four areas: demonstrations, activities, teacher-initiated inquiries, and student-initiated inquiries. The grid helps define inquiry-based investigations and assists teachers in selecting and sequencing the learning opportunities for students. The grid also shows that not all hands-on activities are inquiry based.

Chapter 6, "Why the Scientific Method Is Important," compares inquiry with the scientific method and scientific problem solving, whereas Chapter 7 introduces the Learning Cycle, a five-step approach to designing lessons that facilitate inquiry.

Chapter 8, "Skills and Knowledge of Inquiry-Based Teachers," presents a rubric for assessing and monitoring four stages of development in becoming an inquiry-based teacher. The rubric identifies several subsets: (a) curriculum and content, (b) lesson presentation, (c) communication, (d) engagement of students, (e) classroom organization, (f) questioning strategies, and (g) assessment procedures in the inquiry process. Each subset is described in relation to teacher strategies from the basic awareness level to the practicing level.

Chapter 9, "Using Questioning Skills in Inquiry," presents questioning strategies that enable inquiry-based learning. Questions are the language of inquiry; thus competence in asking thought-provoking questions and responding to student questions is essential.

In Chapter 10, "Inquiry-Based Teachers Describe the Process," we hear from an elementary school teacher just beginning her journey into inquiry and a college professor who shares her insights about using inquiry. Both describe their experiences, including the joys, the challenges, and the rewards of teaching through inquiry.

Resource A, "Inquiry Resources for Teachers," provides printed and on-line resources for further reading and reference. It is essential that those interested in inquiry-based instruction go beyond the initial stages of understanding inquiry to a level at which they can articulate personal philosophies grounded in research and literature. Linking theory and practice will require additional reading and discourse.

As you work your way through this book, a word of caution: Don't expect to become an inquiry-based teacher overnight. Honing your skills and strategies takes time. I often say, "You need a Crock-Pot to cook inquiry, not a microwave!" In most cases, teachers need 3 to 5 years to perfect their inquiry-teaching techniques. There are no shortcuts. Be patient, and with persistence and peer coaching, you will find yourself becoming more comfortable using inquiry-based teaching strategies and appropriate questioning techniques to bring about instructional changes in your classroom.

According to the *NSES*, 'Teachers can be effective guides for students learning science only if they have the opportunity to examine their beliefs and to develop an understanding of the tenets on which the standards are based" (NRC, 1996, p. 28). This book was written and designed to serve that purpose. Now the inquiry process starts with you, the reader, by inquiring within and examining your own ability to pose and pursue questions.

INQ IRY
We can't spell inquiry without
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—Doug Llewellyn

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1

What Is Inquiry?

Ask a roomful of science teachers to explain the meaning of inquiry, and you will probably get a roomful of different answers. And for that, we should not be surprised, because each one would answer the question according to his or her prior knowledge and experience in inquiry-based instruction. The purpose of Chapter 1 is to examine your present understanding of inquiry and compare and contrast it with the understanding of various national experts. This chapter is quite different from others you may have read about inquiry. In my attempt to model constructivist theory, I'm not going to tell you what you should think inquiry is. Rather, you must construct your own meaning and understanding by confronting your beliefs and attitudes about inquiry and making changes and accommodations to suit your own ideas. So, to begin constructing a definition of inquiry, you must start with your present understanding.

As an initial exercise, write down your present understanding and/or definition of inquiry. You may choose to write several statements on 3-by-5 cards (one statement per card), or you may choose to make a concept map to organize your thoughts.

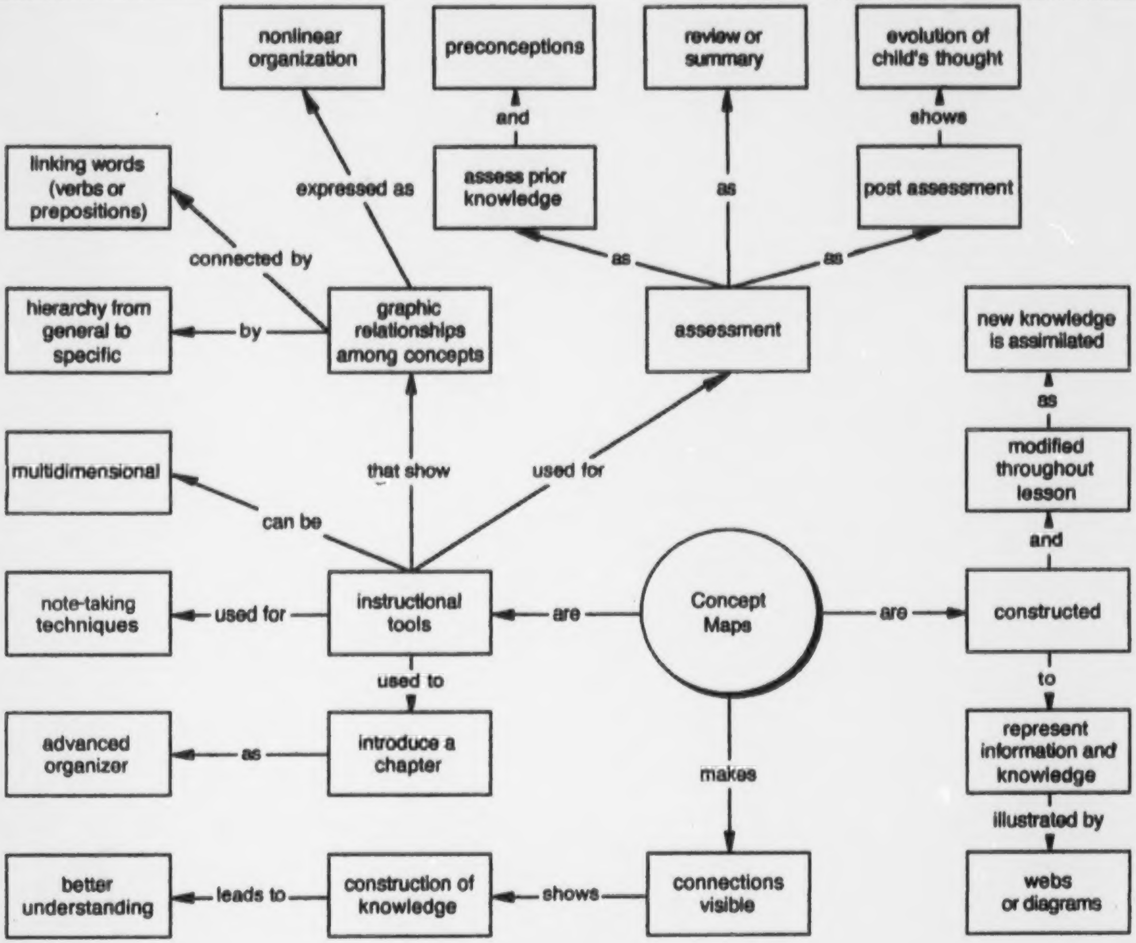
Concept maps (Novak & Gowin, 1989) are schematic diagrams illustrating the relationships and interconnections of concepts for a particular topic. Novak (1998) reports that when teachers and students frequently used concept maps, they learned how to negotiate meaning, organize ideas, and become more effective learners.

When constructing a concept map it is important to

1. Place the main idea at the top or the center of the map.
2. Organize the words or terms from most general to most specific.
3. Use a *linking word* (verb, preposition, or short phrase) to connect and illustrate the relationship and linkages from one idea to another.
4. Use *crossing links* to make connections between words in different areas of the map.
5. Add to the map as new knowledge is constructed (see Figure 1.1).

Whether you use 3-by-5 cards or a concept map, it is important for you to determine your present conceptions regarding inquiry. When you are done, take a few moments and

Figure 1.1. Concept Map



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reflect on your statements and definition of inquiry. At that time, you may want to add or modify them in some way. You will save these statements and come back to them several times throughout the course of this book. Later in the chapter, you will use other statements from the Exploratorium, the National Research Council (NRC), and the American Association for the Advancement of Science (AAAS) to modify and refine your definition. As you continue through this book, you will use a constructivist approach to assimilate new information about inquiry and make accommodations in your own mental model while constructing a personal meaning for inquiry. At the end of this book, you will again be asked to reflect on your statements and definition of inquiry to assess your understanding "pre" and "post."

WHAT THE EXPERTS SAY

The Exploratorium in San Francisco is a hands-on science museum and professional development center for inquiry-based learning. In Fall 1996, the Exploratorium's Institute for Inquiry held a forum in which researchers, teachers, and professional development specialists examined the topic of inquiry from the perspective of their different disciplines—science, mathematics, history, writing, and the arts. Prior to the forum, participants were asked to write short descriptions of inquiry from their professional perspectives. The following are selected descriptions[1] that pertain specifically to science:

> Philosophically, I find inquiry a wonderful metaphor for life. Interacting with phenomena in open-ended ways, following individualized learning paths and noticing everything that occurs, especially the oddities, is a fitting way to go through one's days whether practicing science, the arts, or life. . . . I have become convinced that although inquiry can be a highly personalized experience, it has structures and elements that can be explored and described. The "magic" can be examined and transformed into tools for those who want to teach it and practice it. (Doris Ash, Science Educator, Exploratorium)
>
> Inquiry . . . is a process of exploration which is guided by a personal interest or question. It involves risk taking and experimenting which can lead to pathways where the learner may discover meaningful concepts and understandings. (Marilyn Austin, Teacher-in-Residence, Exploratorium)
>
> Inquiry is practiced naturally from birth as a primary way to develop an understanding of the world around us. Utilizing curiosity and intuition, all of the senses and instincts for observation, seeking and questioning and making use of memory. These are at the same time tools and skills for learning and understanding, which are naturally there but that can also be nurtured and encouraged through guidance. (Daniel DiPerro, Artist/Educator, Exploratorium)
>
> Inquiry, to me, means pursuing a question and figuring out the solutions to problems through a process of observation, development of explanations (theories), testing these through experimentation, discussing the outcomes and adjusting theories based on the outcomes. These various steps are

developed with the participation of all members of the class and always shared and debated in group discussions. . . . By listening to one another, and working to make sense of what others say, students are invited to broaden their notions of the topic and consider new ideas. (Mary DiSchino, Teacher, Graham & Parks Alternative School, Cambridge, MA)

Curiosity is the centerpiece of inquiry, and curiosity is indicated by a question or questions. . . . To inquire is to seek, obtain and make meaning from answers to one's questions. (Hubert Dyasi, Director, Workshop Center, City College of New York, School of Education)

An inquiry approach to teaching stimulates curiosity by teaching children how to observe very closely, encourages children to take more than one quick look, provides adequate materials for exploration, and makes it safer for students to ask questions and to take risks. It helps them to make connections to events in their own lives, and gives them ownership of their learning. I believe that using inquiry can be a means for significant change in teaching in the schools, from providing an education that relies on memorization of facts to one that teaches thinking and problem-solving, and enhances the ability of students to relate what they learn to new problems that come up later. Equally important, teachers need to inquire into their own teaching methods . . . constantly reflecting on their own teaching. (Cappy Greene, Science Educator, Exploratorium)

Inquiry is a major means for learners to extend their understanding of the natural and made environment. It is essentially active learning, inseparably combining mental and physical activity. The motivation for inquiry is within the learner and the learner's relation to the things around him or her. Inquiry starts with something that intrigues, that raises a question—something that is not presently understood, that does not fit with expectations, or just something that the learner wants to know about. . . . The process of inquiry involves linking previous information to the new experience in an attempt to make sense of the new. (Wynne Harlen, Director, Scottish Council for Research in Education, Edinburgh, Scotland)

Science inquiry consists of actions in the world that allow for multiple results. Any activity that is intended to lead to one result only should not be considered inquiry. The definition excludes almost all school laboratory work, because that usually is intended to demonstrate a concept, not general, novel or diverse activity. (George Hein, Director, Program Evaluation and Research Group, Lesley College, Cambridge, MA)

We were born doing science. By randomly touching objects and placing them in our mouths, we learned as toddlers what is hot or cold, sweet or sour, sharp or dull, rough or smooth. We learned almost everything through inquiry. Watching toys sink or float in the bathtub is/was a chance to investigate the principle of buoyancy. By playing catch, we made discoveries about gravity and trajectories. By building towers out of blocks, we explored principles of size, scale and center of mass. . . . Unfor-

> tunately, somewhere along the way we lose our natural curiosity about the world. It seems to happen when we are faced with our first science class. Science becomes a list of facts and formulas to memorize. Our natural instincts to do inquiry are suppressed. (Linda Shore, Co-Director, Teacher Institute, Exploratorium)

Now, go back to your statements and definition of inquiry and compare and contrast them with the statements above. How are your statements or definition of inquiry similar to those of the Exploratorium participants? How are they different? If you agreed with any of the statements you read, add them to your 3-by-5 cards or concept map.

WHAT THE EXPLORATORIUM MEANS BY INQUIRY

The Exploratorium (1998) also provides several statements regarding the definition of inquiry. As you read these statements below, use them to reflect on your own ideas of inquiry and to enhance your understanding. Again, you will be asked to reflect on the Exploratorium's definition of inquiry-based learning and compare it with the definition of inquiry you wrote earlier. According to the Exploratorium,

> Inquiry is an approach to teaching that involves a process of exploring the natural or material world, that leads to asking questions and making discoveries in the search of new understandings. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science.
>
> The inquiry process is driven by one's own curiosity, wonder, interest or passion to understand an observation or solve a problem.
>
> The process begins by the learner noticing something that intrigues, surprises, or stimulates a question. What is observed often does not make sense in relationship to the learner's previous experience or current understanding.
>
> Action is then taken through continued observing, raising questions, making predictions, testing hypotheses and creating theories and conceptual models. The learner must find [his or her] own idiosyncratic pathway through this process: it is hardly ever a linear progression, but rather more of a back and forth or cyclical series of events.
>
> As the process unfolds more observations and questions emerge, giving occasion for deeper interaction and relationship with the phenomena—and greater potential for further development of understanding.
>
> Along the way, the inquirer is collecting and recording data, making representations of results and explanations, drawing upon other resources such as books, videos, and colleagues.
>
> Making meaning from the experience requires intermittent reflection, conversations and comparison of findings with others, interpretation of data and observations, and applying new conceptions to other contexts as one attempts to construct new mental frameworks of the world.
>
> Teaching science using the inquiry process requires a fundamental reexamination of the relationship between the teacher and the learner

whereby the teacher becomes a facilitator or guide for the learner's own process of discovery and creating understanding of the world.

WHAT THE *NATIONAL SCIENCE EDUCATION STANDARDS* SAY ABOUT INQUIRY

In 1996, the NRC released the *National Science Education Standards* (*NSES*). In regard to the inquiry standards, the NRC states,

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

The NRC (1996) standards highlight the ability to conduct inquiry and develop an understanding about scientific inquiry:

> Students in all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (p. 105)

The inquiry standards set forth by the NRC (1996) are divided into three separate grade levels or junctures. Each juncture identifies inquiry standards specific to that grade. The standards help science educators define what students should know and be able to do. Reading and analyzing the inquiry standards for a particular grade level can result in a deeper understanding of inquiry. Reading the inquiry statements from the *NSES* is strongly recommended. The standards can be purchased in softcover (www.nap.edu/bookstore) or downloaded from the National Academy Press. You may also be interested in the accompanying text, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (see Resource A).

Now, go back to your definition and compare it with the statements above. How is your definition of inquiry similar to and different from the *NSES?*

WHAT THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE SAYS ABOUT INQUIRY

In 1990, the AAAS published the first of two documents, *Science for All Americans,* which outlined a long-term view for instructional reform in science. It also marked the beginning of Project 2061 by the AAAS, which proposed recommendations for moving toward the goal of nationwide scientific literacy by the year 2061 (the year of the return of Halley's Comet). Following *Science for All Americans,* in 1993, the AAAS released *Benchmarks for Science Literacy.* It did not define curricular needs but identified specific outcomes for science education and, like the *NSES,* provided local school districts, state education agencies, and national science educational organizations with a blueprint for systemic reform.

Like the *NSES,* Project 2061 addressed the need for integrating scientific inquiry and content. The AAAS (1993) describes scientific inquiry as being

> more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of making a great many careful observations and then organizing them. It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as the scientific method. It is much more than just doing experiments, and it is not confined to laboratories. If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate. But that will require recasting typical school laboratory work. The usual high school science "experiment" is unlike the real thing. The question to be investigated is decided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual); time is not made available for repetitions or, when things are not working out, for revising the experiment; the results are not presented to other investigators for criticism; and, to top it off, the correct answer is known ahead of time. (p. 9)

Like the NRC (1996) standards, the AAAS (1993) benchmarks are divided into separate grade levels or junctures. The AAAS uses four junctures as opposed to three used by the NRC. Both sets of standards are similar in approach and help educators define what students should know and be able to do for the particular content area and grade level. Reading the inquiry statements from *Benchmarks for Science Literacy* is strongly recommended. The standards can be purchased through or downloaded from the AAAS Web site (www.aaas.org). You may also be interested in accompanying AAAS texts, *Inquiring Into Inquiry Learning* and *Teaching in Science* (see Resource A).

MYTHS ABOUT INQUIRY-BASED LEARNING

So far, we have been discussing what inquiry is. Now, we address what inquiry is not by exploring several commonly held myths and misconceptions about inquiry-based learning. If your statements or concept map reveals any of the myths and misconceptions described next, you need to alter them accordingly.

Doing hands-on science is the same as doing inquiry.

Providing students with an opportunity to do hands-on science does not necessarily mean they are doing inquiry. Many science activities are very structured. They tell the students what questions to answer, what materials to use, and how to go about solving the questions or problems. In most cases, they even provide charts or tables to record the observations, measurements, or data. This type of *cookbook* activity provides step-by-step procedures and follows a linear path to a solution. Although most inquiry activities are hands-on, not all hands-on activities are inquiry oriented.

Inquiry is using the scientific method.

As stated by the AAAS (1993), doing inquiry does not necessarily imply following the steps of the scientific method. Inquiry uses the logic of problem solving that comes from the scientific method but does not necessarily use the delineated, specific steps of the scientific method. The scientific method does have a role in the inquiry-based process; however, there is more to inquiry than a sequential set of procedures. Chapter 6 further explains the role of the scientific method in inquiry.

Inquiry is unstructured and chaotic.

In some schools, the sign of a good teacher is one who keeps a classroom quiet and under control. Classroom management skills are essential for inquiry learning, but an active, child-centered classroom should not be equated with chaos or unstructured instruction. When students do hands-on and manipulative-based science, we can expect the noise level to rise somewhat. Inquiry may appear on the surface to be open-ended and unstructured. However, as student involvement increases, so does the need for the teacher to manage classroom movement and communication. When teachers use inquiry-based strategies, they may find that teaching requires more preparation and anticipation of possible student questions than traditional teaching approaches do.

Bell and Gilbert (1996) report that teachers new to inquiry often feel less in control when students move about the room, make decisions about their work, and are encouraged to challenge the work of others. Although most teachers actually maintain control, they may perceive otherwise. To establish inquiry-centered environments, teachers must accept changes in their role and changes in the atmosphere of the classroom.

Inquiry is asking students a lot of questions.

A common misconception held by science teachers is that inquiry teaching requires asking a lot of questions. They may have sat in many science classrooms where teachers fired off question after question. Asking a lot of questions does not necessarily make an inquiry lesson. Chapter 9 presents several examples of effective questioning strategies, such as probing, prompting, and redirectioning, that support inquiry settings. In inquiry-centered classrooms, teachers provide open-ended experiences that lead students to raise their own questions and design investigations to answer them.

If I let my students do inquiry, I have to be ready to answer all the questions they raise.

This is a response of many teachers. Inquiry-based instruction does not just mean finding the right answers, it means seeking the right questions. As you become more confident in using inquiry, you will find yourself less a source of information and more a facilitator of learning. That does not mean that good inquiry teachers do not concern themselves with content. Understanding content and scientific concepts are fundamental to inquiry. Doing inquiry empowers the students to answer their own questions. The teacher becomes the guide and mentor for that process.

Inquiry is fine for elementary- and middle-level students, but high school science teachers don't have extra time in their courses.

For many secondary school science teachers, lecture and discussion methods are the primary means of delivering content instruction to their students. These teachers see lecturing as the most effective and efficient way to transmit large amounts of science information to their students in a relatively short period of time. Lecturing is the method by which many teachers learned science when they were in high school and when they were studying to become science teachers. So, on the basis of prior experience, we should not be surprised that so many science classes are lecture based.

Secondary school science teachers often talk about time constraints. With more and more concepts being added to the curriculum, many science teachers say they are pressed to cover a great number of concepts in a school year. It is true that inquiry-based learning takes more time; however, developing higher-level thinking skills, having students pose questions, plan solutions, and gather and organize data are skills that must be nurtured over time. There are no shortcuts to developing critical thinking skills. To create inquiry-based curricula or classrooms, teachers need to use their time effectively while centering on topics and concepts at the core of the curriculum.

You can't assess inquiry-based learning.

Inquiry-based learning can be assessed like any other concept or topic in science. To assess student progress in inquiry-based learning, however, teachers need to use alternative methods of evaluation. For inquiry-based learning, popular objective-type multiple-choice questions do not adequately assess inquiry-based learning. Inquiry-based teachers often rely on portfolios, writing journal entries, self-evaluations, and rubrics in conjunction with objective-type questions to assess students' academic progress. Examples of each of these alternative assessment measures are presented in Chapter 7.

Inquiry is the latest "fad" for science education.

Those who have studied the history of science education know that questioning, discovery learning, and inquiry date back to the early days of the Greek scholar Socrates. The progressive education reformer John Dewey is credited as being one of the first American educators to stress the importance of discovery learning and inquiry (Dewey, 1900, 1902, 1916). In his early work, Dewey proposed that learning does not start and intelligence is not engaged until the learner is confronted with a problematic situation. Inquiry was also the basis for several elementary science programs funded by the National Science Foundation in the mid-1960s. During this "golden age" of science education, programs such as Science—A Process Approach (SAPA), Elementary Science Study (ESS), and Science Curriculum Improvement Study (SCIS) were all based on the philosophy of integrating inquiry teaching and learning with science process skills.

On the secondary school level, premier high school biology programs such as the Biological Sciences Curriculum Study (BSCS; 1970) are deeply rooted in instructional methods of learning that stress the importance of inquiry-based instruction.

Inquiry is "soft science" and not content related.

We sometimes hear critics of inquiry-based instruction call inquiry "science lite" or sarcastically ask "Where's the beef?" Inquiry, according to both the *NSES* and *Benchmarks for Science Literacy*, is one of the areas identified as content. That elevates inquiry to the same level as knowing the concepts, principles, and theories of life, earth, or the physical sciences. According to the AAAS (1990),

> Science teaching that attempts solely to impart to students the accumulated knowledge of a field leads to very little understanding and certainly . . . science teachers should help students to acquire both scientific knowledge of the world and scientific habits of mind at the same time. (p. 203)

If students are to gain an appreciation for science and compete in a scientific and technical society in this new millennium, they will need to be provided with a curriculum that promotes active learning, problem solving, raising questions, and seeking ways to solve their questions. Inquiry-based science is an effective means to enhance scientific literacy. Additional research has led to the conclusion that inquiry promotes critical thinking skills and positive attitudes toward science. Although inquiry is no panacea, it is one more strategy teachers can use, at the appropriate time, to engage students in investigations and satisfy their curiosity for learning (Haury, 1993).

Inquiry is for high-achieving students and not for students with learning disabilities.

The recommendations set forth by both the NRC (1996) and the AAAS (1993) apply to all students regardless of age, cultural or ethnic heritage, gender, physical or academic ability, interest, or aspirations. The AAAS (1990) stresses that the recommendations apply in particular to those who have historically been underrepresented in the fields of science—mainly students of color, females, limited-English-proficiency students, and persons with disabilities. According to *NSES*, "Given this diversity of student needs, experiences and backgrounds, and the goal that all students will achieve a common set of standards, schools must support high-quality, diverse, and varied opportunities to learn science" (NRC, 1996, p. 221). The ability to think creatively and critically is not solely for the high-achieving student. Inquiry-based instruction can and should be done equitably at all levels.

INQUIRY AS A THINKING SKILL

Learning through inquiry empowers students with the skills and knowledge to become independent, lifelong learners. Finding solutions to their own questions will also allow students to gain an appreciation for the discovery process. Through discovery, students are easily able to assimilate and anchor their prior experiences and knowledge with newly formed experiences and knowledge.

Hunkins (1995) says,

> The good thinker, possessing attributes enabling him or her to create and use meaning—to add to knowledge and culture—possesses a spirit of inquiry, a desire to pose questions central to [his or her] world. The good thinker ponders [his or her] world, actual and desired, querying things valued and desired. (p. 18)

Hunkins goes on to say,

> These individuals realize that productive inquiry essentially starts with the articulation of personal concerns or questions. In many ways, this is a major shift, for students have been taught to wait for the authority, usually the teacher or textbook author, to furnish the problem, define the questions, and suggest the solutions. Indeed, in many schools, students are not challenged to make meaning; rather, they are asked to remember the meaning of others. (p. 19)

Hester (1994) reminds us that inquiry involves

> Critical thinking processes such as methods of diagnosis, speculation and hypothesis testing. The method of inquiry gives students the opportunity to confront problems and generate and test ideas for themselves. . . . The emphasis is on ways of examining and explaining information (events, facts, situations, behaviors, etc.). Students when taught for the purposes embodied in inquiry, are encouraged to evaluate the usefulness of their beliefs and ideas by applying them to new problem situations and inferring from them implications for future courses of action. (pp. 116-117)

"INQUIRING WITH FRUIT"

Now that we have expanded our understanding of inquiry, let's consider a hypothetical group of eighth-grade students exploring the properties of fruit, raising questions, testing their ideas, and discovering new concepts in density. The objective of this lesson is to allow students to explore the properties of fruit and raise questions to investigate. In this session, students are given the task of predicting whether a particular group of fruits will float or sink when placed in a 2-gallon tub of water. (The names of the teacher and students are fictitious.)

During the lesson, Mr. Roberts assesses the students' prior knowledge and preconceptions about fruits that float and sink. He poses the question, "What would happen if I place this apple in the tub of water?" The unanimous response is that the apple would float. By demonstration, their prediction proves correct. Next, it is time to move on to less familiar fruits. Each student has an opportunity to observe (using all five senses) a lemon, a kiwi, a grape, a banana, an orange, and a mango and make predictions about whether each one would float or sink when placed in a tub of water. After the students assign each fruit with either an F or S marked on their worksheets, they *pair and share*, exchanging their fruit predictions. During this part of the activity, students must provide explanations of their thinking to support their individual predictions. Differences in predictions are discussed to produce a group consensus for each fruit. At the end of 10 minutes, each group is asked to record its predictions, test each fruit, and record its observations.

As the students test each prediction, they record their results by constructing a table with two columns, *floaters* and *sinkers* (see Figure 1.2).

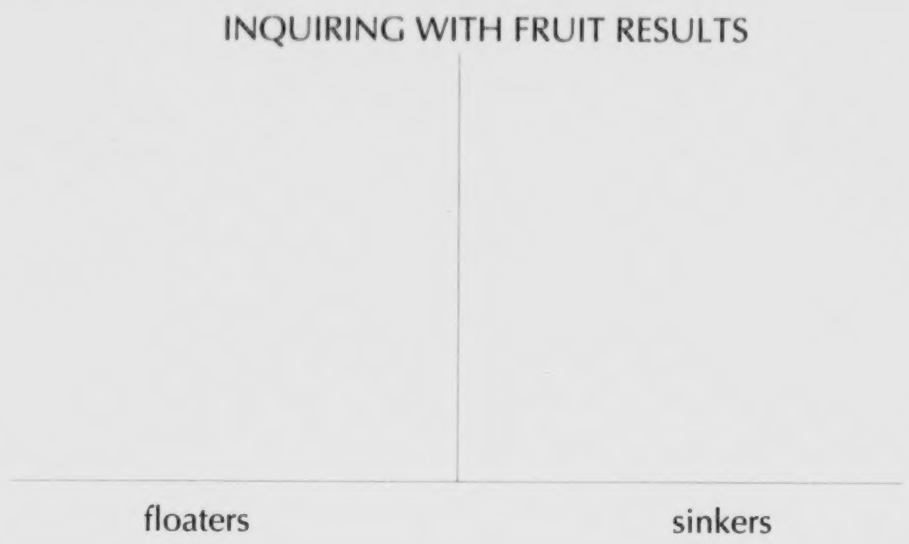
At this point, Mr. Roberts encourages the students to go beyond the initial exploration and raise their own "What if" and "I wonder" questions. In one group, Kayla asks, "Does the outer peel of a fruit affect whether it will float or sink?" She leads her group through a brainstorming session to determine ways to test whether a peeled versus an unpeeled banana will float or sink. They decide to place one peeled and one unpeeled banana in the tub and compare the results. They soon observe that both bananas float and conclude that the peel makes no difference.

As Kayla observes the floating banana with the ends pointed downward in the water, she calls Mr. Roberts over to her table and asks why the banana floats upside down (see Figure 1.3).

Mr. Roberts probes her thinking to determine the root of the question. Kayla admits that she thought the banana would float with the ends upright, like a "banana boat" (see Figure 1.4). Roberts quickly realizes that she was using her prior understanding about bananas and boats to predict that the ends of the banana would float upright, like a boat!

Kayla's group proceeds to discuss floating and sinking in relation to the term *density*. They all know that objects less dense than water float and objects more dense than water

Figure 1.2. Floaters and Sinkers



sink. Mr. Roberts suggests that they apply the principle to the floating banana. There is still confusion, however, about why the banana doesn't float like a boat. Frank poses the question to the teacher, "What would happen if we cut the banana in half?" Rather than answering the question, Mr. Roberts assumes that the group can answer the question without his help, so he responds, "How could you find out?" Frank shares his thoughts about the floating banana and suggests a procedure to test his question.

As the group decides on a plan of action, Frank pulls the banana from the tub and cuts it in half. Just before Frank is about to place the two halves back in the water, Mr. Roberts says, "Wait! What do you think will happen to each half of the banana?" Debbie predicts that each half will float with the pointed end downward. Rob asks her to support her prediction. Debbie responds by saying that the ends will probably act the same as they did when the banana was whole. Figure 1.5 shows how the two halves look after they're placed in the water.

The observation spurs "Wows" and more "What if" questions. Next, Sara asks, "What if we cut each of the halves in half again?" Frank then cuts each banana in half again and, just before lowering the banana quarters into the water, he jokingly asks the other group members, "What is going to happen when I drop these two halves into the water?" Their inquiry leads to more observations (see Figure 1.6).

Seeing the ends of the banana at the bottom of the tub and the two middle quarters floating on top leads the group to conclude that the banana must be more dense at the ends and less dense in the middle. They analyze their results and use an illustration to draw a model of the density of a banana (see Figure 1.7).

Having their observations fit their newly developed model, the group members are confident that they understand why the banana floated "upside down." Mr. Roberts suggests that the group look up the formula for density and actually measure the mass and volume of the banana pieces to confirm its model mathematically and share its discovery with the rest of the class. Excited with their new findings, Kayla, Frank, Debbie, Rob, and Sara search their textbooks for the formula for density.

Figure 1.3. Banana Floating With Pointed Ends Down

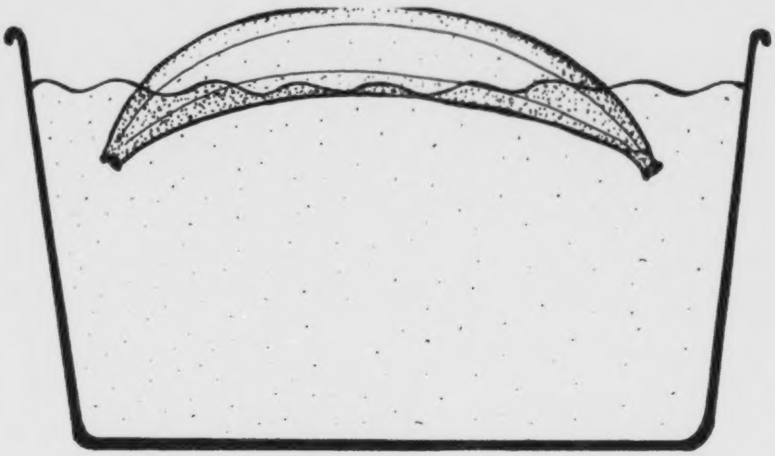
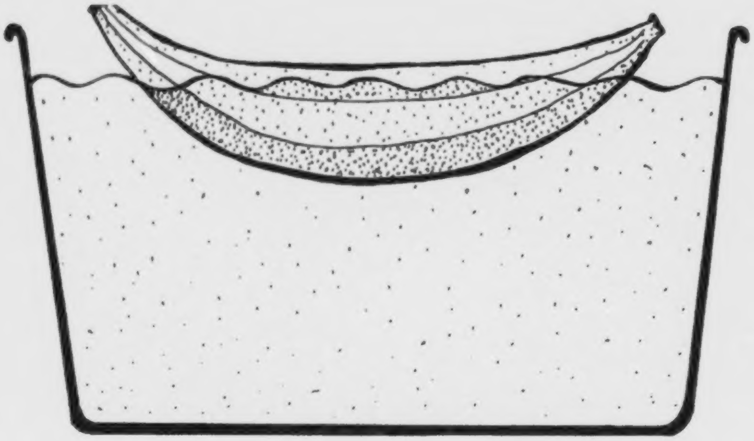


Figure 1.4. Banana Floating With Pointed Ends Up



THE INQUIRY CYCLE

"Inquiring With Fruit" is just one example of an exploration that encourages students to raise questions. In analyzing the group's work, the *inquiry cycle* shown in Figure 1.8 represents aspects of most inquiry-based investigations:

1. *Inquisition*—stating a "What if" or "I wonder" question to be investigated
2. *Acquisition*—brainstorming possible procedures

Figure 1.5. Two Halves of a Banana Floating

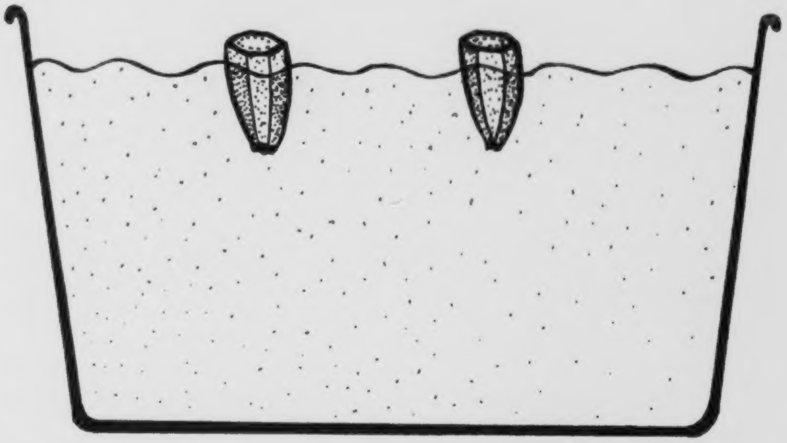
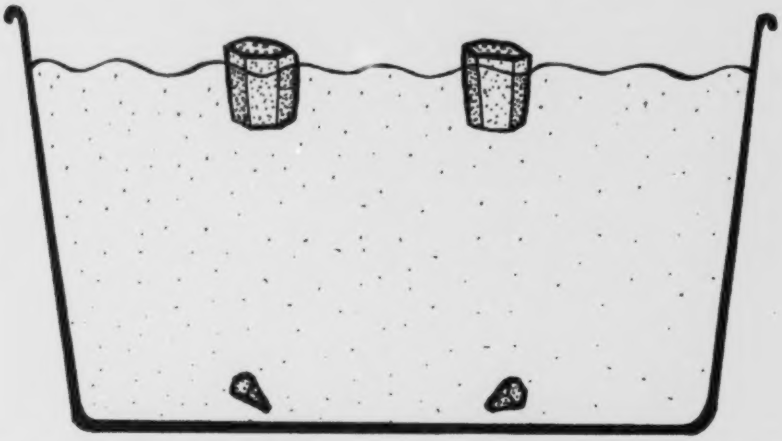


Figure 1.6. Banana Pieces Floating and Sinking



3. *Supposition*—identifying an "I think" statement to test
4. *Implementation*—designing and carrying out a plan
5. *Summation*—collecting evidence and drawing conclusions
6. *Exhibition*—sharing and communicating results

During the inquisition phase, students usually initiate their inquiry by posing a question. It is often stated as a "What if" question and can originate from observing an open-ended exploration, a discrepant event, a demonstration, or a teacher-directed activity. Teachers often plan explorations that end with an observation that is counterintuitive to the student's normal experience. The event seeds a *disequilibrium* in the student's mind

Figure 1.7. Model of Banana Density

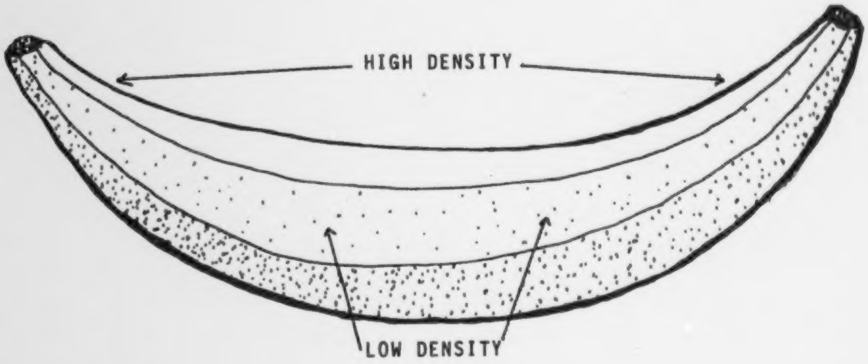
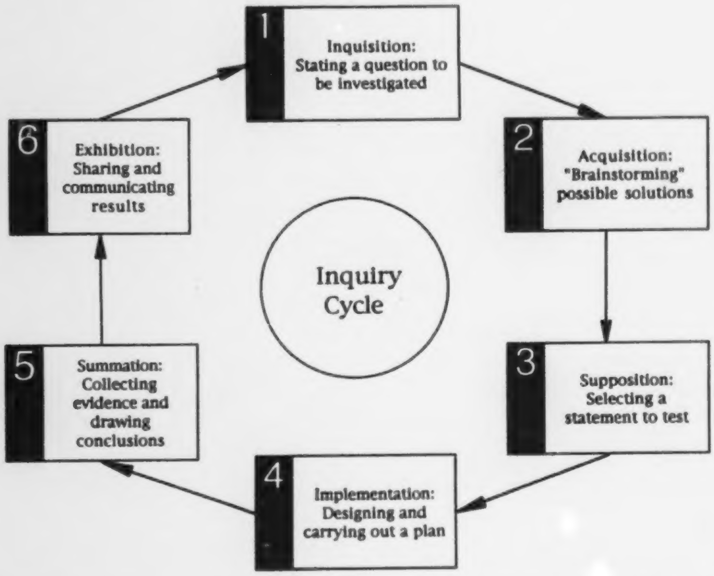


Figure 1.8. The Inquiry Cycle


1 Inquisition: Stating a question to be investigated
2 Acquisition: "Brainstorming" possible solutions
3 Supposition: Selecting a statement to test
4 Implementation: Designing and carrying out a plan
5 Summation: Collecting evidence and drawing conclusions
6 Exhibition: Sharing and communicating results
Inquiry Cycle

and causes him or her to ask "Why?" Educators often call this a *teachable moment,* when the student raises a question and opens his or her mind to imagination. In the "Inquiring With Fruit" investigation, the inquisition phase is initiated by the predicting activity.

During the acquisition phase, students rely on their prior experience to brainstorm possible solutions to the inquiry. Here students ask, "What do I already know about this situation that could help answer the question?" In the acquisition phase of the fruit activity, Kayla's prior conceptions about bananas and floating affect how she perceives the outcome of the group's question.

During the supposition phase, students consolidate the information under study to propose an "I think" statement. This phase generally includes a design of the plan to answer the question under investigation. During the fruit activity, Frank provides leadership to the group in identifying possible statements to test.

During the implementation phase, students design a plan to solve the phenomenon in question and carry out the plan.

During the summation phase, students record and analyze their observations to compare them with the original "What if" question. Mr. Roberts also encourages further investigations by suggesting that the group confirm its results by calculating the density of each banana piece. During the summation phase, students are often led to other discrepancies and "What if" questions, returning the group back to the inquisition phase.

During the exhibition phase, the students communicate their findings and new information in the form of a written report, a poster display, or an oral report. In the fruit activity lesson, the group is anxious to share its discovery and new knowledge about density.

The inquiry cycle can serve as a general format for teachers planning inquiry-based investigations for their students. You should be reminded that the model serves as a general approach to raising and answering questions. Following the inquiry cycle, students often enter and reenter the phases at different aspects of their inquiry process. Thus the cycle serves as a model to guide students through their inquiries and investigations.

A DEFINITION OF INQUIRY

To me, inquiry is the science, art, and spirit of imagination. It can be defined as the scientific process of active exploration by which we use critical, logical, and creative thinking skills to raise and engage in questions of personal interests. Driven by our curiosity and wonder of observed phenomena, inquiry investigations usually involve

- Generating a question or problem to be solved
- Choosing a course of action and carrying out the procedures of the investigation
- Gathering and recording the data through observation and instrumentation to draw appropriate conclusions

As we communicate and share our explanations, inquiry helps us connect our prior understanding to new experiences, modify and accommodate our previously held beliefs and conceptual models, and construct new knowledge. In constructing newly formed knowledge, students are generally cycled back into the processes and pathways of inquiry with new questions and discrepancies to investigate.

Finally, learning through inquiry empowers students with the skills and knowledge to become independent thinkers and lifelong learners. Teachers can encourage students to use communication, manipulation, and problem-solving skills to increase their awareness and interest in science and set them on their way to becoming scientifically literate citizens.

The inquiry approach requires a different mind-set and expectations on the part of the teacher. Later, we describe the role of the teacher and the student in inquiry-based classrooms in more detail.

NOTE

1. Excerpts from Exploratorium (1998). *Inquiry Descriptions.* Reproduced with permission. © Exploratorium®, www.exploratorium.edu

2

Learning Through Inquiry

Real classroom stories often show how inquiry-based lessons progress. This is the story of a fourth-grade teacher who introduces an exploration to her class that (a) allows them to investigate the properties of ice and (b) provides them with opportunities to generate more questions to investigate.

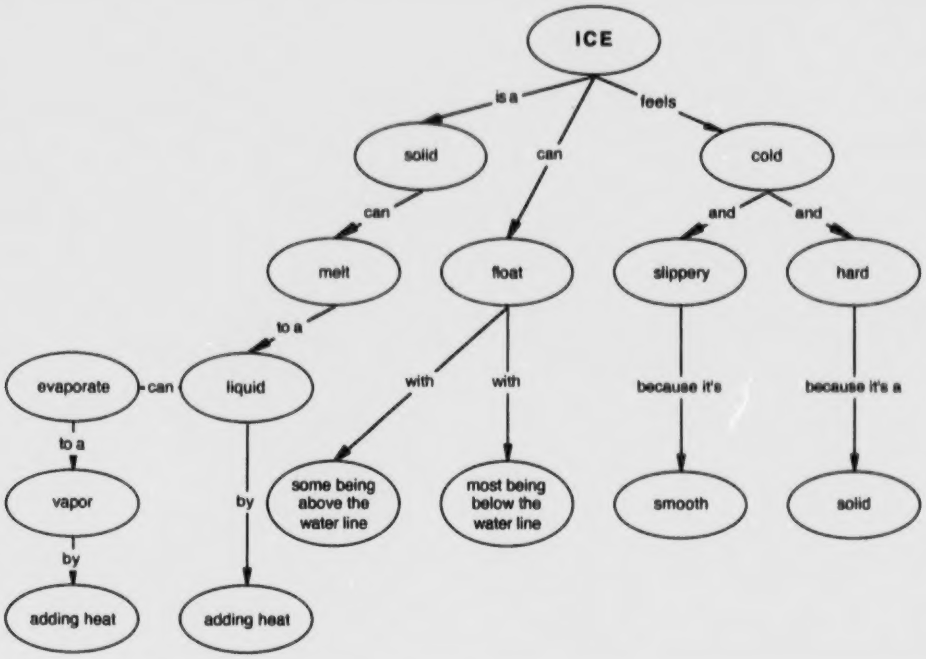
DAY 1: EXPLORING ICE HANDS

"I hope they're ready," Ms. Camille Perlo thought as she opened the freezer door. There, she saw seven frozen hands. Actually, they were *ice hands* she had made the night before by filling latex surgical gloves with water and tying the ends with twist ties. Ms. Perlo took the ice hands out of the freezer, wrapped each one in a kitchen towel, and carefully laid them in a red picnic cooler. Then, it was time to leave for school.

As the bell rang at 9:00, 22 fourth graders made their way to Ms. Perlo's class in Room 139. "Today," Ms. Perlo said, "we are going to start a special science unit. We are going to investigate ice hands and see what we can discover about ice. This is going to be a very special unit because all of you are going to become real scientists and do the things scientists do. To start us off, let's first think about what we already know about ice. Take out your science journals and write down five things you know about ice."

The students quickly opened their journals and began to write. After a few minutes, Ms. Perlo had the students pair and share. This activity gave each student an opportunity to exchange what he or she knew about ice with another person in the class. After a few minutes, Ms. Perlo said, "Okay, who would like to share with the rest of the class and tell them what you know about ice? Michael?" "It's cold and slippery," Michael answered. "Good, I'll write that on the board. Anyone else?" Several hands went up. Nicole said that ice floats in water. Robbie said that ice is the solid form of water. As all the students were given an opportunity to answer, Ms. Perlo wrote and arranged their comments on a con-

Figure 2.1. Concept Map Showing Students' Prior Knowledge About Ice



cept map on the board (see Figure 2.1). Pointing to the concept map, Ms. Perlo said, "See, as a class, we already know a lot about ice."

"Today," Ms. Perlo continued, "you are going to use the information you already have to make investigations about ice hands." Although Ms. Perlo's class had prior experience with doing hands-on science, this was their first inquiry-based scientific investigation. She divided the students into six groups with three or four students to a group. Ms. Perlo gave each group a plastic kitty litter pan and one ice hand. After removing the latex glove that formed the hand, she placed the ice hand in the pan and instructed the students to start to make observations. "Magnifying lenses and rulers are available at the science center for those who want to make closer observations and measurements," she said. The young scientists began making observations and recording data in their science journals. As Ms. Perlo moved about to each group, she noticed the observations and measurements the children were recording in their journals:

> "There are little bubbles and streaks inside." (Karima)
> "Inside the ice hand, little tiny swiggly lines look like hair strings or bacteria." (Terry)
> "One side is flat and the other is rounded." (Renee)
> "It's 5½ inches wide." (Savannah)
> "From the pointer finger to the end of the hand it's about 7 inches." (Dominick)

After giving the students 15 minutes to make their observations, Ms. Perlo said, "I'm going to come around to each of your groups and fill your pan about half full with water. After I do this, you need to place your ice hand in the water and continue to make observa-

Figure 2.2. Photo of Students During Ice Hands Activity

Figure 2.3. Photo of Students During Ice Hands Activity

tions and measurements about your ice hand. Keep recording your results in your science journals." She suggested that they may want to add drawings or illustrations to show how their ice hands change (see Figures 2.2 and 2.3).

While observing the hands in the water, students continued to record their observations:

"It floats in water." (Nicole)

"In water the fingers and hand are starting to melt, but slowly." (Emanuel)

"The little pointy finger is shrinking." (Kyle)

"The fingers are getting pointy." (Katie)

While the students were making their observations, Ms. Perlo asked them to make a list of any questions they had. "Think of several questions you would like to investigate about ice. It may be about the melting or freezing rates of ice. Then write them down in your journals. Later, we will go over the questions and decide which ones you want to investigate."

As she rotated from group to group, the students shared their observations and investigative questions. In about 20 minutes, all the ice hands had melted and it was time to share their discoveries. One by one, each group shared what they had observed and what questions they wanted to investigate. Ms. Perlo wrote all their questions on the chalkboard.

After all the questions were recorded on the board, she reviewed each question and with the students' help, sorted them into categories that (a) were ready to be investigated, (b) needed further revision, and (c) could not be answered without assistance from an outside *expert*.

Each young scientist then had an opportunity to choose an appropriate question to investigate. "I want to see if crushed ice melts faster than block ice," Ariene said. Katie was certain she wanted to be with the group that tried to freeze a bubble!

"Now," Ms. Perlo said, "since this might be the first time you have done a real experiment on your own, let's take one question and work it through as an example." She took one question and led them through a lesson on how to design an experiment so that only one variable would affect the results of the investigation.

Ms. Perlo: Let's take the question, "Does the amount of water affect the time it takes water to freeze?" Tony, how would you start to answer that question?

Tony: I'd try to see which takes longer to freeze . . . a lot of water or a little water.

Ms. Perlo: Good, how could you do that?

Tony: I'd take a big jar and a little jar and . . . fill them both with water.

Ms. Perlo: And then what would you do next? Robbie?

Robbie: I'd place them both in the freezer and see how long it takes for each one to freeze.

Ms. Perlo: That's good. How could you measure the freezing rate?

Robbie: I don't know . . . watch it, I guess.

Ms. Perlo: Is there any way to measure the freezing rate?

Students: [No response]

Ms. Perlo: Maybe use a small stick or something like that?

Renee: Yeah, you could use a little toothpick and poke the ice to see if it's frozen or not.

Ms. Perlo: That's a good idea. Now, would you use the same shape containers for both? Kayleigh?

Kayleigh: I guess so. Yeah . . . one container would be full with water and the other would only be . . . say . . . half full.

Ms. Perlo: *But why would you have to use the same shape container in both cases?*
Nicole: *Because the shape of the container might affect how the ice freezes . . .*
Ms. Perlo: *[Silence]*
Nicole: *And it would make it a fair experiment.*
Ms. Perlo: *Good! Now, would you put them in the freezer at the same time?*
Class: *Yessss. [In unison]*
Ms. Perlo: *Would you put regular tap water in one container and bottled water in the other?*
Class: *Noooo. [In unison]*
Ms. Perlo: *Would you put the container in two separate freezers?*
Class: *Noooo. [In unison]*

After the children understood how to set up a *fair* experiment, it was time to move on to their own inquiries. The class formed groups consisting of three to four students for each of the questions to be investigated. Mark, Justin, Emanuel, and John wanted to find out how long it took ice to melt in regular water versus salt water. Dominick, Terry, Jesse, and Thomas wondered if ice melts quicker in your hand or in water. Kathy, Katie, and Kayleigh wanted to figure out if they could make soap bubbles freeze. Savannah, Nicole, Renee, and Elizabeth decided on investigating whether ice will melt faster in or out of water. Robbie, Michael, Kyle, and Tony wondered if ice would float or sink in regular water versus salt water; and Karima, Ariene, and Regina wanted to know if crushed ice melted faster than block ice.

DAY 2: PLANNING AN INVESTIGATION

On the second day, the children worked in small groups deciding how they would go about answering their investigative questions. "Use your scientific minds to brainstorm a list of steps," Ms. Perlo told them. "And remember to make a list of the materials you need to complete your investigation."

As the groups discussed how to design the procedures for their investigations, Ms. Perlo circulated around the room checking their progress. She reminded the students to think ahead about how they were going to make their observations and collect their data. "When you do that," she reminded them, "it helps you to think about how you are going to organize your results in a data table or chart."

By the end of the science lesson's second day, all the groups had completed their plans and were excited about their investigations. They had thought about their questions and were ready to put their ideas to the test!

DAY 3: CARRYING OUT THE PLAN

On the third day, the students were eager to get going on their investigations. As soon as morning announcements were completed, the students started assembling their materials and carrying out their investigations.

In one corner, Kathy, Katie, and Kayleigh blew bubbles into a plastic container. They thought that by putting the container in a freezer, the bubbles would freeze. They experi-

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mented with containers that were dry inside and others that had been moistened inside with bubble solution. They soon discovered on their own that the container had to be moist inside in order to keep the bubble from popping.

Across the room, Tony, Terry, Jesse, and Thomas were putting an ice cube in a glass of water. They placed another ice cube in each of their hands and held it there. They measured the time it took for ice to melt for both situations.

Savannah, Nicole, Renee, and Elizabeth were busy setting up a way to measure whether ice melts faster in or out of water. They decided to place one ice cube in a glass of water and another ice cube in an empty glass of the same size (see Figures 2.4 and 2.5).

Robbie, Michael, Kyle, and Tony investigated whether ice would float or sink when placed in regular water versus salt water. Their question came from a prior discussion in which one of the group members shared his understanding that objects float "better" in salt water than in regular water.

Next to them, Mark, Justin, Emanuel, and John wondered whether salt water affects the melting rate when comparing it with ordinary water. They were busy measuring equal amounts of water for both cases (see Figure 2.6).

The hammering in the room came from Karima, Ariene, and Regina. They wanted to know if crushed ice melts faster then block ice.

As Ms. Perlo looked around the classroom, each group was busy carrying out their investigations, collecting data, and recording results. She was very proud of her fourth-grade scientists as they worked together, enjoying a morning of discovery.

Figure 2.4. Photo of Thermometers During an Ice Experiment

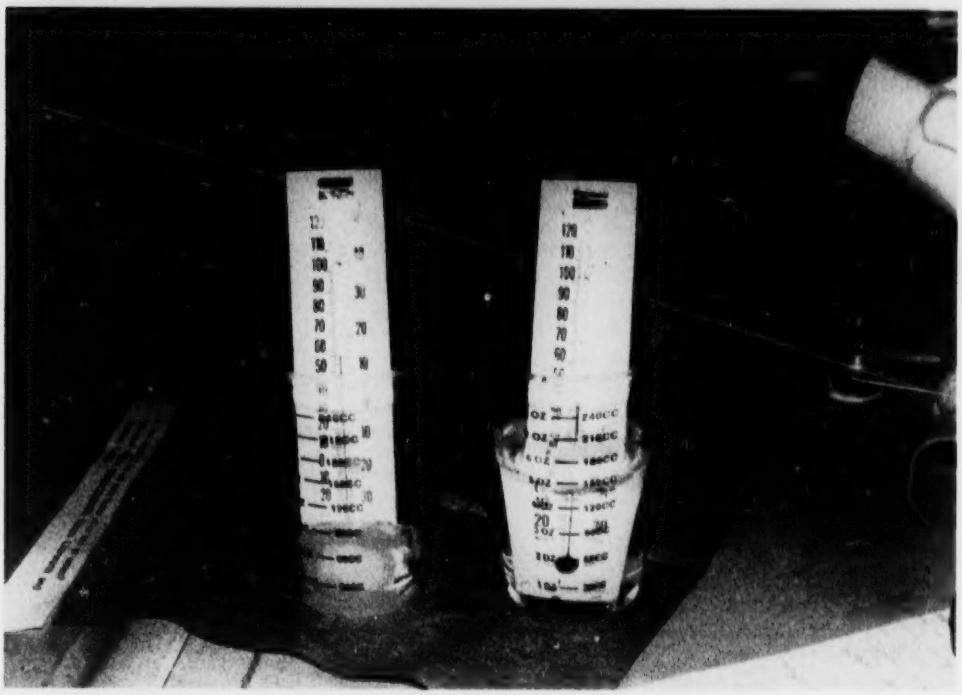

Figure 2.5. Photo of Students Conducting Ice Experiments

Figure 2.6. Photo of Students Conducting Ice Experiments

DAY 4: ORGANIZING THE DATA

By the fourth day of the lesson, all the investigations had been completed. Now, it was time to start the sharing and communicating phase of the inquiry. "Review the results of your investigation and draw a conclusion based on the data," Ms. Perlo told the class. "Remember, all your notes go in your science journals." Ms. Perlo suggested that the groups organize the information from their investigations on trifold display boards.

"The left side of your display boards should state the question you were investigating and your hypothesis," she explained. "The middle section lists the materials used and the steps of the investigation. The right side of the board lists the data table and results. Don't forget to write a concluding statement about your hypothesis," she added. "Be ready to give your presentations tomorrow" (see Figure 2.7).

DAY 5: COMMUNICATING THE RESULTS

The day of the inquiry presentations was a special day for Room 139. One at a time, each group made its way to the front of the room, anxious to share what it had learned (see Figure 2.8). As each group made its presentation, Ms. Perlo carefully recorded on a separate sheet of paper all the new information the class had learned about ice for the next, and final, day's lesson.

Later, the students debriefed on their investigations and reviewed what they had learned. Acting as *reflective friends,* they gave one another comments on the oral presentations. Ms. Perlo brought out the original concept map depicting what the students knew about ice on Day 1 (see Figure 2.9). Students added their newly acquired knowledge about ice to the concept map.

Figure 2.7. Photo of Students Completing a Display Board

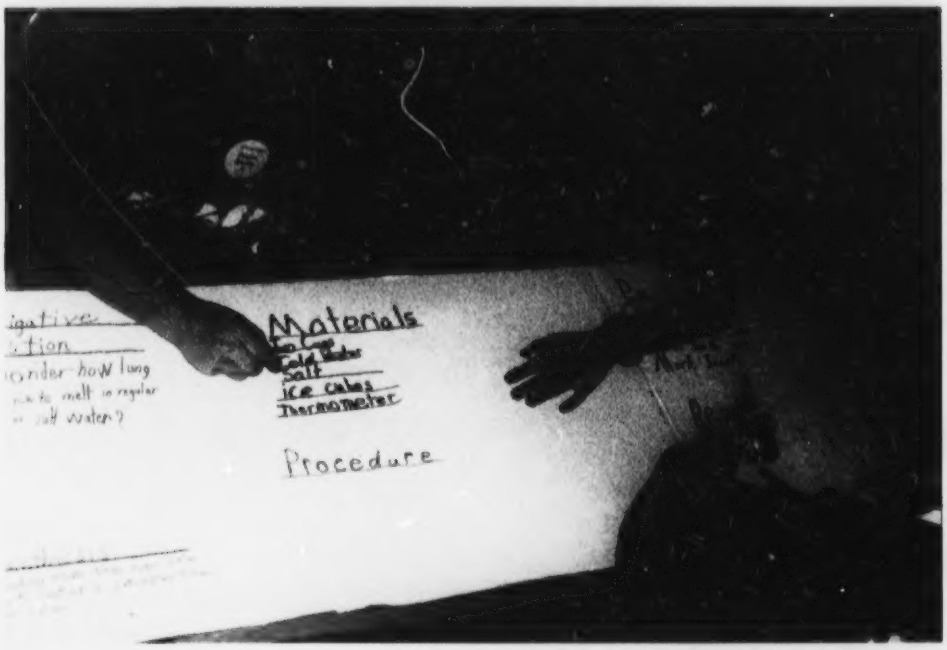

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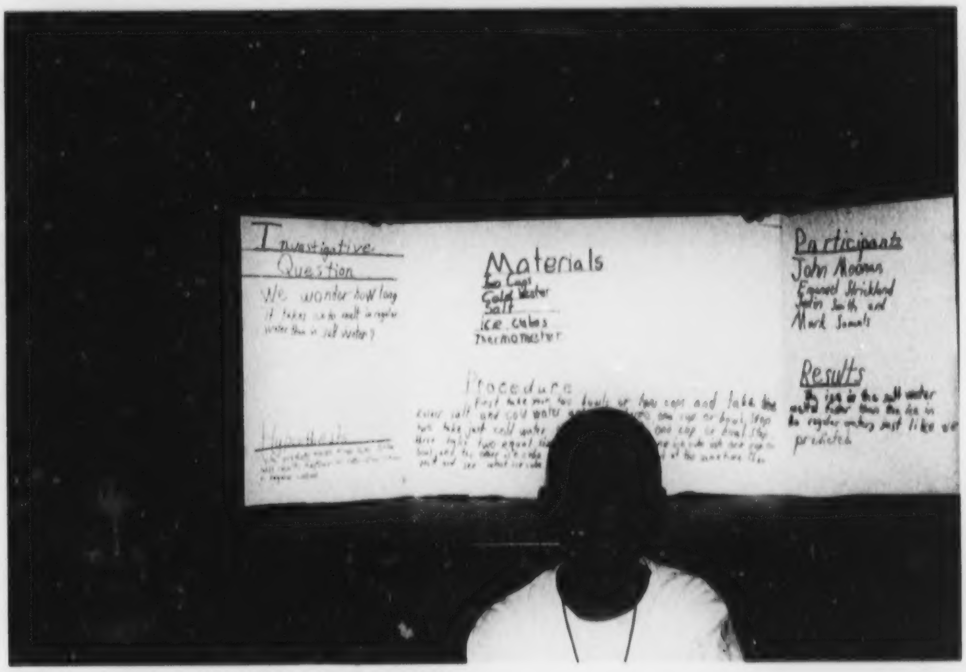
Figure 2.8. Photo of Students Presenting Their Findings



Ms. Perlo also made a list of the vocabulary terms that had arisen during the investigations and wrote them on the chalkboard. These terms became part of the students' spelling words for the week: *density, expand, weight, color, erode, solid, luster, hypothesis, liquid, size, temperature, width, float, ruler, height.*

The students then applied their new knowledge to other situations. For example, they wanted to know how icebergs were formed and how big they are. That led to students wanting to know more about the ocean liner *Titanic* and what caused the "unsinkable" ship to go down on the night of April 14, 1912.

Students also raised other questions about ice:

Why does ice float?
Would placing a fan alongside an ice cube affect the time it took the ice to melt?
Does an ice hand melt faster in or out of the latex glove?
How long does it take water to freeze?
Does the size of the container affect the time needed to freeze?
Does hot water freeze faster or more slowly than cold water?
Does salt affect the freezing rate of water?
How does the freezing rate compare among water, milk, detergent, and soda?
Does the size of the ice cube affect how fast it will melt?
Does the temperature of the air affect how fast an ice cube will melt?
Does stirring make the ice cube melt faster?
Does the temperature of the water affect the melting rate?

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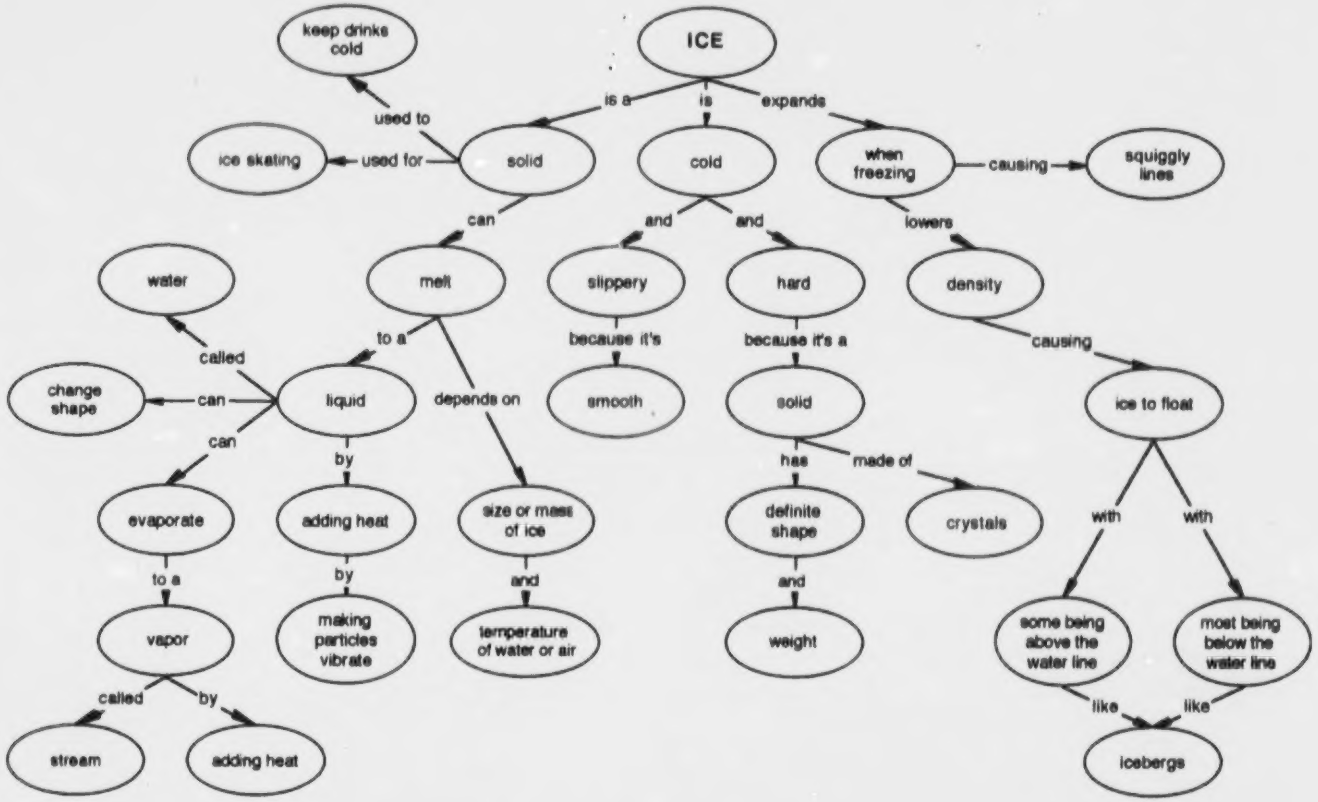
Figure 2.9. Concept Map Showing Students' New Knowledge About Ice



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Does an ice cube melt faster in or out of its container?
How can you make an ice cube melt faster?
How can you keep an ice cube from melting?
Will twice as much ice melt twice as slowly?
Will ice melt faster in a gallon of water or a quart of water?

Ms. Perlo encouraged the students to continue their curiosity by investigating these questions during their free time and after school.

CONCLUSION

At the close of the ice hand inquiry, Ms. Perlo collected the students' science journals. She used the journals as a way of assessing their progress on writing and note taking. She also distributed a self-evaluation form (see Form 2.1) to the students to understand their view on how well they had worked during the ice hand investigation.

Success in learning science can best take place when the students are actively and thoughtfully immersed in the learning process. Ms. Perlo summed up her experience by saying, "This investigation certainly aroused the students' interest and curiosity about ice. Now they are more apt to investigate and discover on their own because the students were genuinely engaged in the subject."

Inviting inquiry in the classroom provides students with opportunities to raise their own questions, plan the procedures, collect evidence, and communicate the results of their investigations. This is just one story about how teachers can use an open-ended exploration to facilitate inquiry-based learning. We refer to the ice hand investigation again in a later chapter to demonstrate how students can explore and investigate science in meaningful ways. For other stories about teachers sharing the excitement and challenge of bringing inquiry into the classroom, I recommend *Inquiry Works! Real Teachers, Real Stories* (see Resource A).

In the next chapter, you will use the ice hand story to blend your personal understanding of inquiry with constructivism, a theory on how children learn.

FORM 2.1

SELF-EVALUATION FORM FOR "ICE HANDS": AN INQUIRY UNIT

Name: ______________________________

Shade in the circle that best describes your experience.

	Almost Always	*Often*	*Sometimes*	*Rarely*
I handled the ice hands properly.	○	○	○	○
I made accurate observations of the ice hands.	○	○	○	○
I made accurate drawings of the ice hands.	○	○	○	○
I followed the procedures in my inquiry plan.	○	○	○	○
I participated in the group discussions productively.	○	○	○	○
I listened to other members of my group and respected their ideas.	○	○	○	○
I did my share of the group work.	○	○	○	○
I used my journal to record my observations and measurements.	○	○	○	○
I used the supplies and materials appropriately.	○	○	○	○
I used many sources to collect information about ice hands.	○	○	○	○
I shared what I learned about ice hands with others in my class.	○	○	○	○
I listened to other members of my group and respected their ideas.	○	○	○	○
I shared responsibility during the ice hand presentation.	○	○	○	○
I made good eye contact during the ice hand presentation.	○	○	○	○
I projected my voice during the ice hand presentation.	○	○	○	○

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3

What Is Constructivism?

DEVELOPING A MIND-SET FOR INQUIRY

To become an inquiry-based teacher, it is essential to develop the proper philosophical mind-set that accompanies inquiry. For many teachers, the principles of constructivism lay the foundation for understanding inquiry. This chapter (a) introduces the philosophical and historical developments that have shaped our understanding of how children learn science and (b) presents a learning theory aligned with inquiry- and learner-centered classrooms.

Becoming an inquiry-based teacher usually starts with a "gut feeling" about good instruction. Sooner or later, however, it becomes equally important to understand what it is about inquiry that complements your style of teaching. Teachers interested in inquiry should be encouraged to articulate their philosophies of teaching. This chapter introduces constructivism, a theory on how learning occurs and how misconceptions can influence learning. This chapter also presents the historical developments of constructivism through the works of Dewey, Piaget, and Ausubel.

WHAT IS CONSTRUCTIVISM?

To *construct* an understanding of constructivism takes time and reflection. Before we discuss what constructivism is, let's start with what constructivism is not. Consider a traditional, teacher-centered science classroom in which communication flows from the teacher to the student and *teacher talk* dominates the lesson. In this classroom, students might sit in straight rows of desks facing the front of the class and have few opportunities to interact or work in cooperative learning groups. In teacher-centered classrooms, students are often passive learners and receive information according to what the teacher feels they need to learn. Information is shared with students predominately through reading and hearing.

The students' time is consumed with note taking, handouts, and worksheets that emphasize basic thinking skills. The teacher in this class often relies on a single textbook that, along with lectures, serves to inform students of the body of knowledge that exists *out there* in the world of science. The activities and laboratory experiences serve as recipes to verify or confirm already stated knowledge and show how a set of scientific principles or *truths* apply to life. In the end, all students are expected to learn the same information. The unit test at the end relies on multiple-choice questions to inform the teacher about which facts and information the students have retained—only to be forgotten within a few days.

Most of us can recall times when we sat in classes like these. In traditional, teacher-centered classes, the focus of learning patterns a behaviorist model. In a behaviorist model, the teacher thinks of learning as observable changes in behaviors. The behaviorist teacher breaks down the curriculum into preplanned *smaller pieces* of information. The teacher then determines how to evaluate and reward (or punish) the student for his or her performance in understanding the new information. This theory has dominated educational practices for most of the past century. It is based on the belief that behavior and learning can be predicted and controlled by the teacher through sequencing the content or skills of the lesson from simple to more complex. In a behaviorist model, the acquisition of knowledge is assumed to be *imparted* from the teacher to the student. In a behaviorist classroom, the teacher assumes that the student's mind is like an empty vessel or a sponge, ready to soak up everything that is said.

Contrary to behaviorism, constructivism takes a more cognitive or *brain-based* approach. In a constructivist classroom, emphasis is placed on first knowing that knowledge is not transferred directly from the teacher to the students. Rather, knowledge is built (or constructed) by the students according to the prior experience and understanding they bring to the lesson.

In contrast to traditional classrooms, teachers in constructivist classrooms know that students bring a varied set of personal experiences, concepts, and understandings to the unit. Constructivist teachers realize that prior conceptions brought to class are often based on misinformation or naive understanding of complex subjects. Uncovering these misconceptions or naive conceptions forms the foundation of a constructivist lesson. To do so, constructivist teachers provide experiences in which students share their presently held theories with their peers. Students can then test their understanding through cooperative group work and inquiry-based investigations.

Constructivism is a theory about how we come to know what we know. It is founded on the premise that children, as well as adults, search for and construct meaning from the world around us. We do this by reflecting on our experiences. In this way, each of us constructs our own mental models as we make sense of our experiences.

In a constructivist classroom, the teacher sees the student as an active participant in the learning process as he or she attempts to search for meaning by linking prior knowledge with new ideas and information.

CONSTRUCTIVIST LEARNING MODEL

Lorsbach and Tobin (1992), believe that constructivism can be useful to teachers when used as a referent or a way to make sense of what students see, think, and do. Regardless of whether you believe in behaviorism or a constructivism, your personal beliefs affect your professional practice in the classroom.

Unlike the behaviorist approach, which focuses on changing behavior through repetition, reinforcement, and factors outside the learner, the constructivist approach places a high priority on factors inside the learner, such as cognitive experiences. The constructivist teacher understands that prior experiences (a) have a profound effect on students as they actively attempt to understand the reality of their world and (b) influence how they interpret new information and experiences and connect them to prior learning.

A constructivist learning model begins with an active and engaging process that provides an opportunity for the learner to create meaning from an experience. That process may include involving the individual's senses with parts of a particular phenomenon. Through exploration and "messing about," the student uses present cognitive structures, ideas, theories, and beliefs to act on and interpret the experience. The individual can also make predictions about the phenomenon by applying prior learning to the new experience. Often, the experience matches the individual's past experience, and the new information is assimilated into the learner's understanding. Other times, the student raises a question, makes a prediction, and tests an understanding—but goes on to record observations and measurements that point out a discrepancy or difference between the predicted and the observable results. This causes disequilibrium, forcing the individual either to (a) discard the observable results because they don't fit into his or her present beliefs or (b) make accommodations within his or her present cognitive structure to allow the new knowledge to replace the previous. Thus the individual has made changes in the way he or she perceives and understands a particular concept or phenomenon. This is called the *conceptual change model.*

THE CONCEPTUAL CHANGE MODEL

To provide a nonscientific yet simple example of conceptual change, consider a child's belief in Santa Claus. Young children often hold on to this belief for many years because what is said and shown to them about Santa *fits* their present beliefs. Seeing images of Santa on television or in magazines or visiting Santa in the mall helps children assimilate *reality* into their cognitive structures. In cognitive theory terms, *all is well,* and a state of equilibrium exists. The reality of the outside world matches the children's cognitive beliefs.

Sooner or later, however, children hear conflicting stories from other kids on the bus or from friends at school that there really isn't a Santa Claus. Or maybe they begin to question how Santa can get around the entire world in one night. Because peers exert considerable influence on how children develop and form their beliefs, children begin to question their theories. What results is a discrepancy between their present beliefs and the contradictory beliefs of friends. By comparing and contrasting their own beliefs to those of their peers, children begin to recognize other possible models and beliefs. This conceptual change results in accommodations or changes in their understanding of a concept. When the new model appears to fit their observations better than the old one, the prior conception is replaced or modified.

Children may be able to state the scientific theory they have been taught yet still personally embrace their own beliefs. This kind of behavior occurs in science classrooms all the time. The Annenberg video *Private Universe* provides an excellent example. Unfortunately, without extended probing, teachers may not be able to determine whether students are actually stating their understanding of a concept or providing the answer they feel the teacher is looking for.

CAN I CHANGE MY MIND?

From their earliest years, children develop an understanding about the world around them through observation, inquiry, and discovery. They observe drops of liquids, pushes and pulls, earthworms on a sidewalk after a rain, shadows, and just about everything around them. They formulate their understanding through sensory experiences. This knowledge enables individuals to make interpretations about the world around them as they view the world through their personal *lenses*. As constructivist teachers, we know that these lenses attempt to filter out all experiences that do not fit with presently held beliefs. As stated earlier, children are personally and emotionally attached to their beliefs and do not give them up easily. The authority of teachers is usually not strong enough to change many of the misconceptions held by students. That is to say, just because something comes out of a teacher's mouth and goes into the ears of students does not mean that students will accept it.

Challenging children and causing them to modify misconceptions takes a considerable amount of patience and persistence. What we do know is that peers can sometimes be strong motivators for giving up misconceptions and undergoing cognitive conceptual change. We must also remember that peers have their own naive conceptions and often share them in social settings. In classroom situations involving constructivist and inquiry-based learning, engaging in discussion at the start of the lesson is one way to understand students' beliefs and possibly uncover their misconceptions. But simply uncovering misconceptions may not be enough. We need to become aware of students' misconceptions and adjust our teaching accordingly.

Children come to understand and interpret their world through observing and inquiring with the help of their friends, classmates, and peers. Dialogue, discussion, and communication with peers during inquiry makes the construction of knowledge a social experience. Discussion provides a forum in which previously implicit beliefs can be shared, made explicit, tested, and reflected on. It provides a situation in which students can clarify their own notions in the process of discussing their ideas with others. The student modifies, reorganizes, and reconstructs his or her ideas through experiences, talking, and listening.

Students will change their conceptual structures (misconceptions) when there are adequate incentives. According to Posner, Strike, Hewson, and Gertzog (1982), students will change their conceptions when

- They become dissatisfied with their existing conditions
- The scientific concept is intelligible
- The scientific concept appears plausible
- The scientific concept is useful in a variety of new situations

MISCONCEPTIONS: WHAT YOU KNOW MAY NOT BE SO

Everyone has beliefs and biases. They are in part based on information, understandings, and concepts we hold at any given time. Here is one example of how children construct meaning: This past summer, my 7-year-old nephew, Brandon, visited my family at our cottage. Brandon was spending the weekend with us, and I had promised that I would take him fishing. So, early Saturday morning, we packed up our fishing poles, the tackle box, and a Styrofoam cup filled with earthworms and headed down to the lake. Arriving at the dock, we found a spot where the fish were certainly going to be. After all, it was breakfast time, as Brandon told me, and the fish had to be hungry.

As we sat on the edge of the dock with our poles dangling just above the surface of the still morning water, Brandon looked down at the worm on his hook and asked, "How long does it take the worms to grow up?" "What?" I asked. "The worms, you know, the baby snakes. How long does it take the worms to grow up to be snakes?" Wow, I thought to myself, what a unique thought for a 7-year-old: worms growing up to become snakes!

For many individuals, especially young children, such concepts are often derived from commonsense interpretations of experience, thus forming what are called naive concepts or misconceptions. For Brandon, it made perfect sense to connect earthworms and snakes. After all, they look and act alike. It would seem to be a logical conclusion.

Many kids enter our classrooms with a host of misconceptions about the world around them. Uncovering and addressing the misconceptions that kids bring into our schools has received much attention in modern education theories and instructional systems. Duit and Treagust (1995) suggest that "at all ages students hold conceptions about many phenomena and concepts before they are presented in science class. These conceptions stem from and are deeply rooted in daily experiences because they have proved to be helpful and valuable in the daily life" (p. 47). In fact, children are often quite satisfied with what they think they know and don't question their present notions. Duit and Treagust go on to say, "Very often, however, these conceptions are not in accord with science concepts. Research has shown that students do not switch easily from their old preinstructional conceptions to the new science concepts taught" (p. 47).

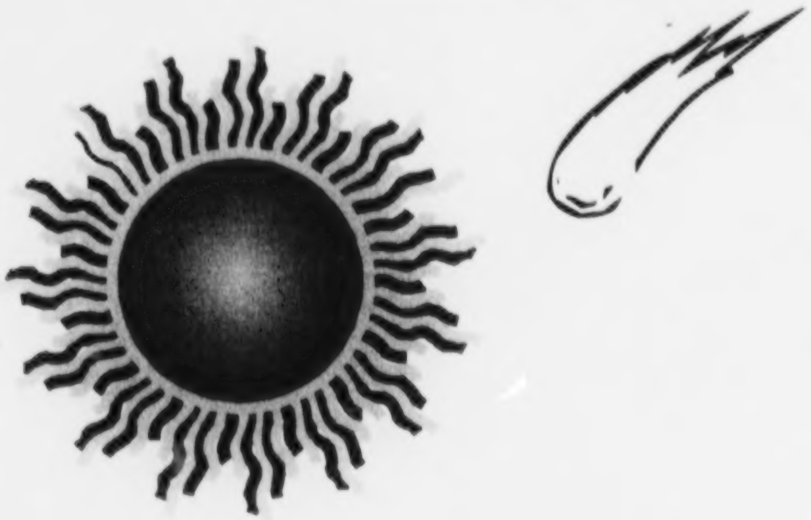
Listening to children express their misconceptions can also be quite humorous at times. This is the premise for the television show *Kids Say the Darndest Things*. With host Bill Cosby asking the questions, children's ideas about life often prove to be funny as well as educational.

Scores of examples of misconceptions have been identified in recent research about science teaching. Phillips and Soltis (1991, p. 21), in identifying misconceptions in earth science, point out that before beginning classroom instruction, the teacher must uncover misconceptions commonly held by students. With 20 to 30 students in a class, this can be a difficult and sometimes impossible task.

Let's take the study of comets as an example. Students have probably seen pictures of comets in science textbooks and magazines. When asked to determine the direction in which a comet is traveling, students often use the "tail" of the comet to answer the question. Because prior experiences about rockets show a stream of gasses or fumes escaping from the base of the rocket, the steam is always opposite the direction the rocket is traveling. Many students apply that same logic to comets and assume the tail is behind the comet. Actually, the tail of the comet is formed by solar winds blowing back on the evaporating gases as the comet "melts." The comet's tail tells us where the sun is in relation to the comet because the tail is always pointing away from the sun (see Figure 3.1).

To explain this to young children, the teacher can stand in front of a floodlight or some other bright light source and have students observe the position of the teacher's shadow. Regardless of whether the teacher is walking toward or away from the light (or sun), the shadow (or tail) is always pointing away from the light source. Thus the tail of the comet does not indicate the direction the comet is moving; it indicates only where the sun is in relation to the comet. When students can actually see the shadow and compare it with their prior experiences with light and shadow, their misconceptions about comet tails may be dispelled.

Figure 3.1. Comet's Tail Pointing Away From the Sun



WHERE DO MISCONCEPTIONS COME FROM?

As children begin to make sense of their world, they start by observing and interpreting phenomena. These experiences are processed and recorded in various locations of the brain—in the visual, auditory, and motor cortices—not just in one specific place (Wolfe, 1998). Interpretations are sometimes based on deductive reasoning. When the deductive reasoning results in an understanding that is not matched to a scientific explanation, the interpretation is called a naive conception or misconception. Misconceptions can come from a variety of sources: direct experience, television, books, peers, and even adults. Because these misconceptions are usually based on personal experiences, they are often deeply rooted and difficult to modify.

Media are often sources of children's misconceptions. Turn on a *Road Runner* cartoon and watch all the laws of physics being violated. And after watching numerous episodes of the *Flintstones,* children may tend to believe that humans and dinosaurs lived during the same time. Movies can also provide viewers with the wrong information. Some movies show cavemen hunting dinosaurs even though scientific evidence tells us that most dinosaurs were probably extinct 60 million years before human life evolved on the planet. When starting a unit on dinosaurs, teachers need to address these misconceptions in a way that makes sense to children.

Even school textbooks can foster misunderstandings and misconceptions. In one classroom activity, third-grade students were following the directions in a science text for making a collage on the phases of the moon. To complete the collage, students were instructed to make cardboard cutouts representing the various phases of the moon: full moons, half moons, and crescents. In the procedure of the activity, the students were directed to tie the cardboard moon phases to strings and hang them on clothes hangers (see Figure 3.2).

The teacher questioned one student about the moon's phases and how they change. The student explained that the moon gets larger and smaller. Although the student could not explain where the rest of the moon went or where it came from, she just knew that it changed shape.

This obviously was a misconception brought about by some prior experience and reinforced by the collage activity. A suggestion for the revision of the activity would be to cut out full circles to represent the moon and darken the areas of the moon that are not lighted

Figure 3.2. Cut-Out Moon Phases on Hanger

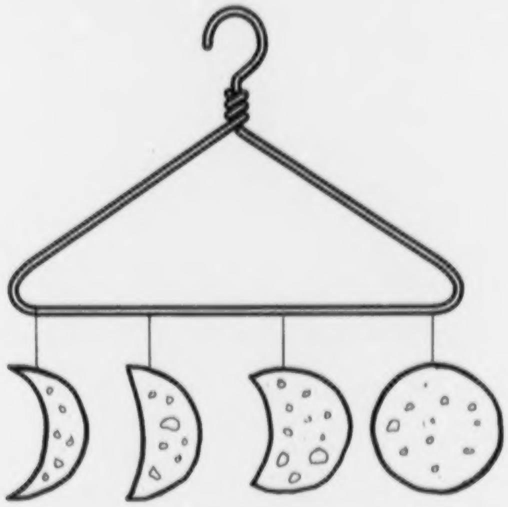
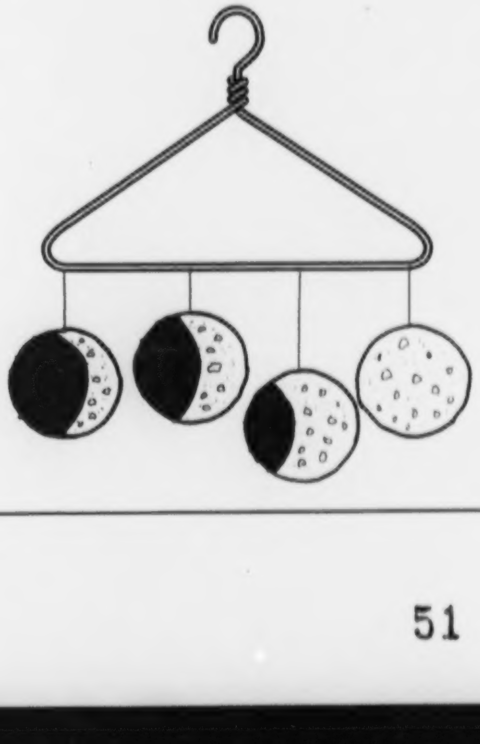


Figure 3.3. Darkened Moon Phases on Hanger



(see Figure 3.3). This way, students could see that the entire moon is present, although some of its surface cannot be seen.

The revision could be followed by the teacher using a light source, a globe, and a Styrofoam ball to simulate the rotation of the moon and the cause of its phases. Many science resource books contain information for setting up this demonstration.

Because oral language is a primary source of information for children, their own peers and sometimes adults or teachers can also be sources of misconceptions. Consider the conversation between two 8-year-old girls as they plant bean seeds in a container:

Genna: We have to put lots of dirt in the container if we want the seed to grow into a plant.

Karen: How do you know?

Genna: 'Cause when we add the water and fertilizer, it will give the plant food to grow.

Karen: Oh yeah?

Genna: Yeah. That's how the plant gets its food . . . from the dirt. It's the same as earthworms eating the dirt.

Karen: That's cool. I didn't know that.

In this case, the students appear to have a common yet limited knowledge of plant growth and food production. The relationship between the plant's basic needs (air, water, and minerals) and the production of food still needs to be developed during additional science lessons. Rather than the teacher telling the students that the plant manufactures its own food in the leaves by photosynthesis, the teacher could prompt the students into an inquiry to discover if plant seeds can grow in a medium other than soil. By planting seeds in cotton balls or paper toweling, the students can observe the seeds germinating without soil. This information and the initiation of a conversation between teacher and student to refine the child's understanding may be the first steps in dispelling the notion that plants need soil to grow.

Everyday language, among both peers and adults, also contributes to shaping a child's understanding of the scientific world. For example, the statement that "The sun rises in the East and sets in the West" conveys a basic contradiction of the simplest laws of planetary physics and reinforces the notion of a helio-centered universe.

COMPARING THE EARTH AND THE MOON

The relative sizes and distances of the earth and the moon are other examples of misconceptions that children and even adults have about our solar system. Through a simple demonstration using a globe and various balls, the size and distance relationships between the earth and the moon can be understood.

Picture a ninth-grade earth science class studying this subject. (Teacher and student names are fictitious.) Mr. Braun uses an inflatable globe, 16 inches in diameter, to represent the earth. This globe works especially well because it shows an actual image of the earth instead of lines of latitude and longitude. Alongside the globe are four balls; one ball is an inch in diameter, the second 2 inches, the third 3 inches, and the last 4 inches in diameter. Showing the earth and the four smaller balls, Mr. Braun poses the question to his students, "If the earth is represented by the inflatable globe, which of the four balls would represent the size of the moon so that the earth and the moon are in correct proportion in terms of their relative sizes?" He asks each student to make an individual prediction and record that prediction on a piece of paper. He then asks the participants to pair and share their predictions with those sitting next to them and give reasons for choosing the sizes they recorded. In doing this, students have to rely on prior knowledge and provide details in support of their predictions—possibly exposing some commonly held misconceptions or naive conceptions about the relative sizes of the earth and the moon. As the students work in pairs, Mr. Braun circulates about the room, listening to the comments being made and mentally noting possible misconceptions. As is to be expected, there is a great deal of variation in the responses of the participants.

After the students have shared their predictions with their partners, Mr. Braun takes a poll of the responses. Of the 25 students, 11 have chosen the 1-inch ball, 6 have chosen the 2-inch ball, 5 have chosen the 3-inch ball, and 2 have chosen the 4-inch ball. One student thought it was a trick question because she thought the earth and the moon were about the same size.

After recording the predictions on a chart, Mr. Braun asks several students to explain their predictions. Most of them respond by telling about how small the moon is and that the smallest ball seemed the best choice. The class is obviously eager to find out which ball is correct. Rather than giving them an answer, Mr. Braun probes the audience by asking, "What information do you need to know which ball is the correct one?" They respond that they need to know the diameters of the earth and moon in miles. He provides information to show that the earth's diameter is approximately 8,000 miles, and the moon's is approximately 2,000 miles. One student, Maria, concludes that the actual ratio of the size of the earth to the moon is 4 to 1. She asks what the size of the inflatable globe is. Again, rather than giving the answer, Mr. Braun hands her a ruler. Maria measures the diameter of the globe as 16 inches. She goes on to explain that because the ratio is 4 to 1, and because the globe is 16 inches, the correct ball must be 4 inches. The other students break out in applause!

HOW FAR IS THE MOON?

The teacher's next question builds on the students' knowledge of the size problem. He asks them, "If the earth is represented by a globe 16 inches in diameter, and the moon is represented by a ball 4 inches in diameter, how far does the 4-inch moon have to be from the 16-inch earth to place them in relative proportion to their distances? Would it be 10, 15, 20, 30, or even 40 feet?" Again, Mr. Braun asks them to make individual predictions. To help them in making their predictions, one student holds the earth, and another holds the moon. The student holding the moon walks across the room to estimate her distance in feet from the earth.

Once again, Mr. Braun uses the pair and share procedure to have students explain their predictions to their partners. Later, the class poll shows that most of the students predicted that the distance between the earth and the moon would be 10 to 15 feet. Again, Mr. Braun asks them, "What information do you need to know to determine the correct distance?" Several students conclude that they need to know the distance from the earth to the moon (240,000 miles). They determine that because the globe represents 8,000 miles, 12 inches or 1 foot would represent 6,000 miles. By dividing 6,000 into 240,000, they determine that the accurate distance between the earth and the moon should be 40 feet! They measure 40 feet and position the inflatable globe and the 4-inch moon appropriately—the length of the entire room apart.

Mr. Braun leads the class into a follow-up conversation that includes a discussion about how demonstrations and group work can help overcome naive conceptions and build new, accurate knowledge.

WHY TEACH TO MISCONCEPTIONS?

In classrooms, misconceptions often go undetected. Unfortunately, teachers receive little training in identifying and addressing misconceptions. Addressing misconceptions is an important part of teaching and learning. If we don't attempt to uncover and teach to students' misconceptions, chances are they will leave our classroom with the same misconceptions they had when they entered the room.

Changing a child's long-held belief about something can sometimes be difficult. Misconceptions are often challenged when a discomfort level or disequilibrium exists between the student's present notion of a concept and new information being presented. Consider once again a child's belief in Santa Claus (Howe & Jones, 1993). Most young children hold on to this belief for many years, although they may question just how someone Santa's size could fit down a chimney or get around to all the houses in the world in just one night. And although their friends may talk about the nonexistence of Santa Claus, children may refuse to stop believing in this red-suited character. In fact, when questioned, children often defend their belief in Santa Claus as opposed to giving it up. Finally, after realizing that not all houses have chimneys, and testing their theories (and misconceptions) against their peers', they begin to recognize the possibility of other models and beliefs and start to make changes and accommodations in their understanding.

Other beliefs commonly held by young children are also difficult for them to give up. These may include the Easter Bunny or the Tooth Fairy. Consider the different theories children have on how babies are born. Some children believe in the "Cabbage Patch" model, and others hold on to the "stork" model or the "baby grows in mommy's stomach" model. If you are a parent, your child may have asked you, "Where do babies come from?" The question may have been prompted by a contradiction between what the child believed and the beliefs held by someone else. The talk young children are given by parents about the "birds and the bees" often creates disequilibrium in their understanding of reproduction. Yet that little talk, as awkward and uncomfortable as it may have been, may not have been influential enough for children to change their beliefs or give up their prior conceptions.

In any case, students should not be laughed at or ridiculed when stating their beliefs, especially when their prior knowledge may be naive conceptions. When students are embarrassed about sharing their ideas, they often withdraw and are reluctant to risk sharing again. This causes students to hold on to their prior knowledge and not expose it to their peers or teachers. Thus for teachers to assess and identify misconceptions, students need an atmosphere in which they can freely express their thinking without being laughed at or ridiculed.

UNCOVERING MISCONCEPTIONS IN SCIENCE

Several instructional strategies can be used to unveil prior knowledge and misconceptions commonly held by students in the classroom. Beginning a lesson by asking students

"What do you know about . . ?" is a technique often used by teachers using the *KWL* method (Olge, 1986). In this method, the teacher organizes the lesson or unit into three questions: "What do you *know* (about the topic)?" "What do you *wonder* (questions to investigate)?" and at the conclusion of the lesson or unit, "What have you *learned?*"

By posing the first question, "What do you know?" the teacher can assess students' prior knowledge and adjust the lesson accordingly. This can be done at the beginning of any class through individual writing or group discussion and charting the responses. Posing such questions to students can also reveal what they know and don't know about the topic they are about to study, which allows the teacher to adjust the lesson or unit accordingly.

The Learning Cycle (Karpus & Thier, 1967) is a teaching and learning model based on the work of Jean Piaget. The Learning Cycle was also used as the instructional model for an elementary science program funded by the National Science Foundation—the Science Curriculum Improvement Study (SCIS)—in the early 1960s. More specific information on The Learning Cycle is presented in Chapter 7.

The model includes a five-step approach to lesson development. The five steps are

- Engagement
- Exploration
- Explanation
- Extension
- Evaluation

During the Engagement stage, the teacher introduces the students to the learning task and focuses on connecting prior knowledge to the new knowledge being presented in the lesson. As the teacher makes this connection, it is an opportune time to find out what prior knowledge and possible misconceptions the children bring to the lesson. Thus the Engagement stage provides an excellent opportunity for the teacher to access prior knowledge and understanding, identify what students already know about the topic, and adjust the lesson accordingly.

Because a student usually answers a question on the basis of his or her prior knowledge and experiences, teachers need to pay close attention to all student responses. Wrong answers generally reflect misconceptions held by students. They often tell teachers a lot more about students' prior understanding than correct answers do.

Addressing a student's misconceptions is not a simple process. First of all, the teacher needs to have a firm grasp of the concepts being studied to be able to recognize subtle misconceptions. Next, the teacher needs to pose questions and carefully listen for misconceptions. The teacher can then plan the instruction to include discrepant events and hands-on experiences that cause the student to question his or her prior understanding.

HISTORICAL DEVELOPMENT OF CONSTRUCTIVISM

Many of you might ask, "If constructivism makes sense, why aren't more teachers using inquiry-based methods?" To answer this question, we must look at the historical development of science education and the early theories about teaching and learning that led us to the present situation. Most teachers and students are products of an educational system that is based on the work of early philosophers from a hundred years ago. Much of our present educational system is predicated on early behavioral studies. By studying educational philosophy, we can begin to understand how today's teachers were taught and how their education influences the way they currently teach in their own classrooms. When studying the historical developments of education, it becomes clear that we, as products of our educational system, are steeped in traditional behavioristic educational philosophy.

We begin our look at the development of education by returning to the concept of epistemology, the philosophy that pertains to the structure and origin of knowledge. We must understand how knowledge is formed to appreciate the potential of inquiry learning as a means for students to gain knowledge. Behaviorism is then compared with constructivism,'a more modern and cognitive approach to understanding how one comes to know. We start by examining some early educational philosophers.

John Locke

John Locke, a British philosopher (1632-1704), developed a theory that laid the foundation for modern psychology. His thoughts had a profound effect on schools and teaching. Locke felt that children are born completely devoid of any understanding. He described the newborn's mind as a blank slate, or *tabula rasa*. Locke believed that the human mind has certain biological abilities but they lie dormant until information is inputted and processed. As the infant inputs more information into the brain, the level of understanding expands and develops. According to Locke, the newborn baby knows nothing at birth but begins to collect information by experiencing the environment through the process of observation, using all five senses to collect data about this new world. As the child continues to make observations, these experiences are recorded and saved in the mind's memory sections. This model of learning was simple to understand and made sense to educators at the time.

The Behaviorists

The next period of educational philosophy was shaped by a new era in which theories were based on scientific testing rather than philosophy. These new theorists based their ideas on observing and testing the behavior of animals under controlled settings. These experiments were directed toward understanding animal behaviors and instincts rather than cognitive developments. Inferences were made about how animals learn and solve problems. The data were used to draw conclusions about how humans learn. This group of theorists, called the *early behaviorists*, heavily influenced educational practices from the 1920s through the 1950s. Their ideas continue to have implications for our present system of education. We look briefly at the work of two leading behaviorists.

Edward Thorndike

Edward Thorndike (1874-1949) was interested in associations between sensations and behavior. He studied the stimulus-response reactions of animals, focusing his research on the instinctive behaviors of cats (Thorndike, 1911). He placed a cat in a *puzzle box* that contained a simple release mechanism. If the cat triggered the release door, it could get out of the box and would be rewarded with food. Thorndike recorded the time it took the cat to escape from the box. He found that on successive trials, it took the cat less time to escape. Thorndike concluded that the cat began to learn what it took to escape and get a reward.

He theorized that (a) the more the cat practiced the escape, the more the cat learned and (b) because the escape had a reward experience, it would increase the cat's escape repetitions. In other words, the more the cat practiced the escape from the box, the better the cat would be able to do it, and as long as the escape had pleasant consequences, the cat would continue to try to escape.

Although Thorndike was not particularly interested in classroom applications of his work, his *transfer of learning theory* was applied by others to instructional settings. It was believed that a behavior could be learned as long as the task was practiced enough and the learning had positive consequences. Thorndike's transfer of learning theory had a prevailing effect on educational systems for the first half of the 20th century.

B. F. Skinner

During the late 1930s, B. F. Skinner, a neobehaviorist, considered learning to be a change in behavior. Unlike earlier behaviorists who made little connection between behavior and instruction, Skinner applied his ideas to suggest ways in which learning occurs and curriculum should be structured. He used the research from Thorndike and applied it to his own study, with rats and pigeons, on the nature of reinforcement principles. He found that a reward did not have to be provided every time a desired behavior was expressed. Skinner found that the behavior would continue even when the reward was provided randomly—in other words, "a little praise can go a long way" (Phillips & Soltis, 1991, p. 27). Skinner believed that when applied to teaching, positive reinforcement could be an incentive for students to demonstrate specific behaviors.

Skinner's *operant conditioning theory* was applied to learning programs designed to reward correct answers and provide remedial exercises for missed or incorrect responses. This type of learning strategy was popularized in self-pacing and individualized learning modules. Later in his research, Skinner would advocate the use of technology and computers to provide individualized, self-paced, programmed instruction in which students would receive immediate feedback and reinforcement for correctly answering questions. Skinner's ideas are evident in behavioral modification strategies used in schools, including classroom management, the use of contingency contracts with students, and the application of behavioral objectives in planning instructional lessons.

More recently, Driscoll (1994) said this about behaviorist theory:

> According to the behavioral perspective, just as we can set goals for appropriate behavior, so can we express in behavioral terms the instructional outcomes we desire students to achieve. In fact, behaviorists would argue the only evidence we have of learning comes from the students' behavior; they can do something after instruction that they could not do before. It is important, therefore, to specify desired instructional outcomes in terms of clear, observable behavior. These goal statements are variously called behavioral objectives, instructional objectives, or performance objectives. (p. 55)

Although much of education today is still shaped by the theories of the behaviorists, the latter half of the 20th century produced a shift away from analyzing behavior and toward a greater interest in understanding cognitive psychology and metacognition. The new theorists argued that learning cannot be attributed solely to the assimilation of new behaviors. The cognitive structures that exist within a child's mind must be considered. They argued that writing and teaching to behavioral objectives does not ensure that learning has occurred. We cannot assume that just because a teacher has presented information, the students have derived meaning from it.

The Constructivists

Recent research on the brain and children's cognitive and social experience have opened the door to understanding how one comes to learn and communicate knowledge. This new era in educational psychology ushered in the cognitive and constructivist theorists.

The earliest constructivist writing, *De antiquissima Italorum sapientia,* dates back to an Italian philosopher, Giambattista Vico, in 1710. Here, we examine the research and philosophy of several 20th-century reformers to learn how they have shaped modern theories about learning.

John Dewey

John Dewey (1859-1952) is considered one of the 20th century's most influential educational theorists and philosophers. His work at the University of Chicago helped shape modern education. Dewey's ideas about education were closely tied to the natural world. Dewey felt that teaching should be an active process, including solving problems that interested students. He believed that problems posed to pupils too often involved the interests of the teacher rather than the students. In Dewey's mind, learning had to have personal meaning for the student. Although he did not deny that some knowledge could be presented to students by their teachers, he did emphasize that each learner needs to make use of knowledge for it to be meaningful and retained. Dewey believed that thinking arises when a person confronts a given problem. The mind actively engages in a struggle to find an appropriate solution to the problem by drawing on the person's prior knowledge and experience, formulating a strategy to solve the problem, and finally, weighing the consequences of that action (Phillips & Soltis, 1991, p. 39). In short, Dewey wanted schools to engage students in meaningful problems.

In applying Dewey's philosophy to today's science classrooms, DeBoer (1991) says,

> Dewey believed all instruction should be organized in such a way that it takes account of what the student knows. Prior student experience is restructured in the mind through a process of interacting with the teacher and the other students. Learning always involves present understanding as a starting point. Insistence on relevance of subject matter to enhance meaningful learning has been part of science education discussions since the late nineteenth century and continues to be a large part of good science teaching today. (p. 223)

Jean Piaget

Jean Piaget (1896-1980) was a Swiss scientist who began his scientific career studying bivalved mollusks. While working at the Binet Institute in the early 1920s, translating intelligence tests from English to French, he became interested in the mistakes children made on the tests. Unlike the behaviorists, Piaget concentrated his work and research on humans, not animals. Although Piaget began researching cognitive development in the 1930s, his theories on cognitive development didn't catch the attention of American educators until the 1960s, partly due to the fact that his writings were in French. By studying how children make sense of their world, his work became a turning point in our thinking about how knowledge is acquired and had a great impact on educators over the last half of the 20th century.

Piaget (1970) believed that knowledge is not *out there* somewhere, waiting to be discovered but, rather, is acquired and constructed through a process of interaction with materials. He studied a number of learners through clinical interviews in which he posed questions and provided problems (later to be called *Piagetian tasks*) for them to solve. He then made careful observations about their solutions and analyzed their comments.

Piaget focused his study on the cognitive structures that enable a child to solve a problem. On the basis of his research, he identified four developmental stages of mental reasoning that characterize the development of knowledge and use of logical thinking. He believed that children construct cognitive representations from their experiences that he termed *schemas.* Schemas are personal mental models that enable us to actively interpret and assess phenomena and incoming information from existing conditions. These schemas are often naive, incomplete, and imprecise. Sometimes, mental models represent scientific views, and sometimes they represent presently held misconceptions. As children experience new information, they use these schemas to assimilate new ideas in constructing knowledge. Driscoll (1994) suggests that schemas are used to make inferences and predictions about other unobserved events. Different from Locke, who believed that children are given knowledge, Piaget (1970) theorized that childern construct their own understanding on the basis of their explorations and interactions with peers, adults, and objects within their environments and come to *know* an object by acting on it.

Piaget's theory is largely based on three assumptions:

1. Knowledge is a result of the ever-changing interaction between individuals and their environments.
2. Intelligence is constantly being constructed from prior and new experiences.
3. Cognitive growth is self-regulating within the individual and the interaction of the physical and social environment.

Although Piaget's theory was never intended specifically for academic teaching, it holds a special interest for teachers, especially science teachers. In studying the transition that children make from concrete to formal operations, teachers understand that students need to explore a new concept through hands-on experiences before being introduced to the terminology and vocabulary associated with the concept. Introducing concrete inquiry investigations first and saving the terminology and vocabulary for later allows children to explore new experiences, test theories and ideas against their peers, and assimilate their understanding. Piaget saw the child as a scientist, exploring and testing the conditions of his or her environment.

According to Piaget, the process of adaptation occurs through assimilation and accommodation. Assimilation involves making use of new information and transforming new knowledge to fit existing schemas and mental models. In accommodation, mental models are altered, modified, or changed to accept or fit the newly perceived knowledge. Adaptation happens when individuals encounter phenomena that are contrary to their presently held understandings. They judge the new events and make adjustments in their cognitive structures to accommodate the new situations. This results in new learning. In most cases, assimilation and accommodation function simultaneously. Piaget refers to this as *equilibrium.* That is, the individual is self-regulating his or her understanding and maintaining stability. At equilibrium, we are at ease with our presently held notions and all is well with the world.

Disequilibrium occurs when we experience new phenomena that do not fit neatly into our presently held schemas or models. Piaget called this *cognitive conflict.*

Constructivists believe that when a new event doesn't fit a child's presently held belief, it can possibly be discarded because it doesn't fit with the child's cognitive model of understanding. Assimilation, accommodation, and disequilibrium are the bases for constructivist thinking and conceptual change. According to Piaget, for conceptual change to occur, the child must be faced with new conceptions that are inconsistent with presently held beliefs. The child must also acknowledge dissatisfaction with his or her present schema and accept the plausibility of the new concept, thus substituting the new concept for the previously held one.

Piaget's theory has been widely accepted in the field of cognitive development as well as in education circles. Applications of Piaget's theory include the following:

- Learning should be active and discovery based.
- Children should be given every opportunity to interact with their peers.
- Instructional strategies should be adapted to fit the cognitive structures of children.
- Conceptual change should be promoted by allowing children to test their presently held theories and become aware of inconsistencies in their thinking when compared with scientific models.

David Ausubel

Ausubel (1968), like other constructivists, viewed cognition as the framework for organizing hierarchical concepts. Ausubel believed that with meaningful learning, linkages are formed or *subsumed* between previous, more general concepts and new knowledge. Meaningful learning occurs when new information is linked (or assimilated) to existing or previous concepts (Novak, 1977, 1998). Oftentimes, information derived without meaningful learning is not retained for long periods after the initial introduction. In the words of the old Chinese proverb, "Tell me and I forget, show me and I remember, let me do it and I understand."

Along the same lines as our previous discussion on accessing prior knowledge at the start of a lesson or unit, Ausubel (1978) said, "The most important single factor influencing learning is what the learner already knows; ascertain this, and teach him accordingly" (p. iv). This serves as a reminder for teachers interested in constructivist learning strategies to begin with the child's perspective as a departure for instruction.

CONSTRUCTIVISM TODAY

Behaviorism so dominated educational culture during most of the 20th century that constructivist principles were not readily accepted, even in the realm of research. Modern brain research offered much to sway the general acceptance of learning from behaviorism to constructivism during the 1980s and 1990s.

Constructivism today has an increasingly significant impact on educational reform and is increasingly being adopted as the accepted theory on how children learn. The ideas of Dewey, Piaget, and Ausubel were largely responsible for the new era of enlightenment in science education during the 1960s through the 1990s.

In summary, key points in constructivism include the following:

1. The senses are conduits to assimilating new knowledge.
2. The learner's existing or presently held understanding determines which new situations are accepted or ignored.
3. The learner's existing or presently held understanding determines how new situations are interpreted.
4. Knowledge is not transmitted from one individual to another. Communication is transmitted, but communication and incoming information are not knowledge. Knowledge is constructed in the mind by the learner attempting to make linkages to previously stored knowledge within the brain.
5. The learner uses linkages to construct new knowledge.
6. The learner's understanding is constantly undergoing construction and reconstruction.
7. Learning is both personally (reflection) and socially constructed (testing one's model against peers).
8. Inquiry is a viable teaching strategy to test the *degree of fit* between one's previously held theories and *scientific* explanations of things.

BACK TO THE ICE HANDS

We now have a better understanding of how inquiry and constructivism go hand in hand. Let's turn back to the ice hand investigation in Chapter 2 and analyze it from an inquiry and constructivist perspective. Here is a summary of the ice hand investigation, in which teacher Camille Perlo enacted the following sequence:

1. She introduced the investigation by saying it was going to be an opportunity in which the students would be doing the things scientists do.
2. She assessed prior knowledge by having students write in their journals what knowledge they brought to the lesson and then had students discuss through a think-pair-share activity. The information was then shared with the entire class by designing a concept map or listing their ideas on the board to include all their presently held understanding about ice.
3. She provided materials with which the students could observe and explore an ice hand in a dry pan while recording observations in their science journals. Later, she added water to the pan so that students could observe the ice hand floating and melting.
4. She encouraged the students to raise and record "What if" and "I wonder" questions.
5. She categorized student questions according to which ones could be answered through experimentation, which ones needed revising before investigating, which ones could be answered best through expert resources (or books), and which ones couldn't be answered at that time.
6. She had students select questions and grouped students around the questions to be investigated.
7. She provided time for students to discuss and brainstorm their investigations through group dialogue and identify specifically what they wanted to find out.
8. She had students write statements to test, in the form of hypotheses or predictions.
9. She provided time for students to design plans to carry out their investigations.
10. She had students collect evidence and data, organize data in tables and charts to look for patterns and relationships, and draw conclusions about their stated predictions or hypotheses.

11. She encouraged students to communicate their evidence and findings by having each group make an oral presentation with a poster board.
12. She compared new knowledge gained through the investigations with prior knowledge by revising and modifying the concept maps made during Day 1.
13. She applied newly acquired knowledge to other situations.
14. She encouraged students to pursue and explore additional questions, thus beginning the cycle all over again.

The process followed during the ice hand investigation represents attributes of both constructivist principles and the inquiry cycle. The unit can be summarized by illustrating the "constructivist" inquiry cycle (see Figure 3.4).

CONSTRUCTIVIST CLASSROOMS

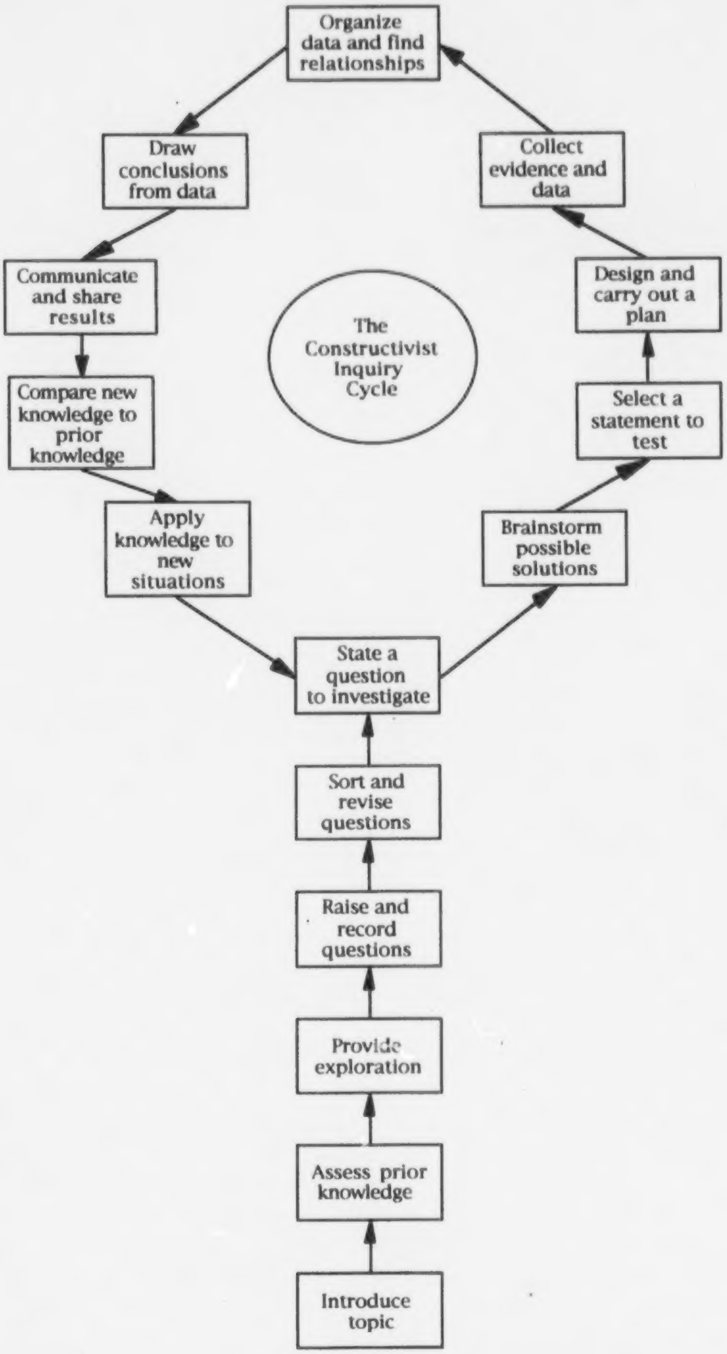
Through the ice hand example, you can see how the notion of constructivism has implications for teaching and learning science. How many of the following characteristics can you identify from the ice hand investigation that portray a constructivist unit of study?

1. Knowing how children learn and its bearing on how we approach teaching and learning
2. Knowing that educational theory places meaning on our understanding about teaching and learning
3. Demonstrating that it is essential to use concrete and manipulative materials to introduce formal concepts
4. Starting with what a child knows as an effective departure point for any science lesson
5. Allowing explorations and time to "mess about" to introduce and sequence new knowledge, thus aligning with present learning theories
6. Encouraging inductive and discovery learning to open the doors to problem solving and higher-level thinking skills
7. Providing challenging activities to students' thinking and problem-solving skills
8. Using active learning in which the student can discover and construct new knowledge
9. Posing "What if" and "I wonder" questions to facilitate assimilation and accommodation
10. Encouraging students to work in groups to share and communicate knowledge and to test each other's ideas and theories, making learning a personal and social experience

HOW SCIENTISTS DO SCIENCE

In this section, we draw an analogy between how a scientist does science and how a child learns. When elementary school children describe or draw scientists, they quite often picture white males with frizzy white hair and white lab coats mixing chemicals in a laboratory. Their idea of a scientist resembles the image of a "mad scientist." Whatever ideas they have about scientists, most students know that they test ideas and try to find answers to the

Figure 3.4. The Constructivist Inquiry Cycle


Organize data and find relationships
Draw conclusions from data
Collect evidence and data
Communicate and share results
Design and carry out a plan
The Constructivist Inquiry Cycle
Compare new knowledge to prior knowledge
Select a statement to test
Apply knowledge to new situations
Brainstorm possible solutions
State a question to investigate
Sort and revise questions
Raise and record questions
Provide exploration
Assess prior knowledge
Introduce topic

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world's questions. Students also know that scientists use skills such as observing, measuring, and experimenting to solve problems.

A more mature notion evokes the image of a person who seeks a broad explanation of a particular unexplained phenomenon, formulated through repeated testing and scrutiny. This explanation is sometimes called a *theory*. A theory, in turn, may be illustrated or represented by a model. Model building is an important aspect of the work of scientists. Models are useful because they help us explain things we cannot directly observe. As our abilities to observe and measure are enhanced, so are our explanations, theories, and models.

Our understanding of the atom is an example of how models change by our changing ability to observe and experiment. The early Greeks thought that all matter was made of four elements: air, fire, earth, and water. This was one of the first "models" of atomic theory, although limited by human intuition. The first "modern" atomic model was proposed in 1911 by British physicist Ernest Rutherford. Rutherford proposed that atoms were composed mostly of empty space! Rutherford's model included a positively charged center surrounded by negatively charged particles called electrons. Later, Niels Bohr proposed a model that became the modern theory of atomic structure. Many of us were taught the Bohr model in high school chemistry class and can recall electrons pictured as particles orbiting around the nucleus like planets in our solar system. With new technological advances in electronic imagery and quantum mechanics, today's atomic model includes subatomic particles, called *quarks*, in various clouds around the nucleus.

Mental and physical models are constructed through direct and indirect observations. Although models help scientists explain scientific phenomena, they are always limited by human senses, tools, and abilities. These observations lead to inferences, and inferences help build theories. Scientists then use these theories to construct models that fit their observations and inferences. As said earlier, as our abilities to make observations are enhanced, so are the models that stem from those observations and inferences. In other words, models are evolving explanations of our natural world. Thus it is best to be cautious about assuming that any model represents reality.

Models do not exist forever. The history books of science are filled with outdated theories and models that were once thought to be "truth." Consider for a moment the second-century astronomer, Ptolemy, who proposed the theory that the earth was the center of the solar system. French biologist Lamarck proposed the theory that the giraffe got its long neck by stretching it to reach the leaves on branches of tall trees. Both of these prominent scientists formulated popular models—only to have them be disproved.

Although some models become outdated on the basis of new observations, other phenomena may be explained by several possible models because of the limited way in which models can be tested. Consider what may have caused dinosaurs to become extinct. Several models exist to explain the disappearance of dinosaurs. The model of an asteroid hitting the earth's surface 65 million years ago near the Yucatan Peninsula in Mexico appears to be one of the most accepted.

In studying dinosaurs, paleontologists continue to rewrite the pages of science. Many of us have visited museums and seen dinosaurs as fierce animals, with their tails on the ground. Recently, new observations indicate that dinosaurs may have been warm-blooded and quite maternal. And many science museums exhibiting *Tyrannosaurus rex* skeletons have had to "redesign" their extinct creatures by repositioning the tails as extensions of the backbone.

In one fourth-grade class, the teacher explained to her students why scientists now know that *T. rex* didn't drag its tail. She explained that because of the lack of tail marks between the footprints of dinosaurs, left in mud fields and preserved as fossils, scientists have concluded that dinosaurs held their tails up—above the ground. The class went on to find more than 50 pictures of dinosaurs shown dragging their tails behind or resting on them. The students later displayed their findings on a poster titled "Misconceptions About Dinosaurs."

Several years back, the phrase *paradigm shift* became popular in describing a change of position in thinking. Corporate leaders used it to refer to a new way of thinking or doing business. *Undergoing a paradigm shift* meant taking on a new way of looking at something. Paradigm shifts are analogous to the way scientists rethink theories and models on the basis of new observations and evidence. We use this idea to introduce a model about how children learn that is similar to the way scientists do science.

HOW CHILDREN LEARN

Although some educators often describe a child's learning as being like "a sponge soaking up knowledge," constructivist teachers see learning quite differently. Constructivist teachers see learning as a process by which the child is a *theory builder*. In the constructivist sense, the child's knowledge is a result of his or her prior experiences, and children learn to make observations about the natural world by using their senses. They use their observations to make sense of the world and draw inferences about cause-and-effect phenomena that they experience. These inferences lead the child to form theories about how the world operates. Thus a child's present understanding or theories are, again, largely based on his or her prior experiences. These experiences allow the child to form models and store them as memories within various areas of the brain.

Children continue to test their ideas, beliefs, and models through ongoing observations. Children often test their theories and models through interaction with their peers, one of the most influential aspects of their life. When their observations and experiences continue to match their presently held theories and those of their peers, the experiences are assimilated and the model is reinforced. When their observations and experiences do not match their presently held theories, (a) the experiences can either be discounted because they don't align with their present understanding or (b) their model can be accommodated by a conceptual change to include this new experience. In other words, they would undergo a paradigm shift!

As we see, understanding learning as a theory builder is similar to the way scientists formulate scientific theories. As scientific theories and models change according to new evidence, so can children's theories. For example, let's again consider how children believe babies are born. Some children begin by thinking that the stork brings little babies. This story might have been introduced by parents or peers. Other children may believe that mommy and daddy go to the hospital to pick out a baby while looking through a window. (After all, you can see all the little babies lined up in their beds behind the window.) Some children may later give up the stork model or the hospital model and believe in the "Cabbage Patch" model. Sometime during their early life, most children adopt the "baby growing in mommy's stomach" model. Much later, probably during science or health class, a child gives up his or her previously held models and accepts the one proposed in school. Similarly, the cognitive models about our world are continuously changing and modifying with new experiences and interactions with others.

Recall the process you went through in Chapter 1, in which you wrote a statement about your understanding of inquiry. The statement was meant to help you reflect on your present understanding and make changes and modifications to your model of inquiry by considering the ideas of other experts. In other words, you were constructing an understanding of inquiry!

According to constructivist philosophy, knowledge is not imparted or absorbed from one individual to another. Rather, knowledge and meaning are constantly being assimilated and accommodated in the minds of cognizing beings through interpretations of their experiences and from verbal communication with others. But if knowledge is imparted through language between the teacher and the students, why do teachers often find themselves teaching a concept one day and discovering the next day that the students just did not "get it"? If my teaching philosophy were based on assumptive learning, I might assume that learning occurs because the students are listening to me, the teacher. But just because students are listening to me does not mean they are always making sense of the words coming out of my mouth. The words may be part of the sender's (the teacher's) experience but not part of the receiver's (the student's) experience. Thus language is an important aspect of learning in a constructivist approach. The child needs language based on his or her previous experience to make sense of what is being said. Consider this conversation between a teacher and a student in which the teacher asks where the child lives:

Teacher: *What's your place of residence?*

Student: *What?*

Teacher: *I said, "What's your place of residence?"*

Student: *Uh, I don't know.*

Teacher: *You don't know where you live?*

Student: *Oh, where I live? I live at 52 Maple Street.*

In this case, "What's your place of residence?" made sense to the sender, the teacher, but did not make sense to the receiver, the student. "What's your place of residence?" was not part of the student's prior experience and language. We now understand that students interpret our language on the basis of their own experience.

According to Piaget's model, children form networks (called schemas) within the brain to store information about their experiences. All incoming information is then translated through a child's schema. As stated earlier, when a new situation arises that is inconsistent with a child's present schema, the child may either (a) disregard the new information because it doesn't fit with the presently held notion or (b) change or give up the previously held notion and accept a new notion based on new evidence. If the child accepts a new model, it is probably more useful, makes more sense, or is more plausible than the previously held model. Keep in mind that children are often reluctant to give up their presently held models and misconceptions in spite of what their teachers or friends tell them. Just as children are reluctant to give up believing in Santa Claus, we are all sometimes very resistant to change.

Sometimes the teacher poses a question, and the student responds with an answer he or she thinks the teacher is looking for. When this happens, the student may not wish to share his or her personally held understanding about a concept. It may be because the student lacks confidence in this understanding or does not want to risk being ridiculed by peers. In other cases, children can hold more then one model about a particular concept. Native American children may hold two separate and distinct models about the formation of the world: a scientific model and a cultural model. The child knows when to provide the scientific model to the teacher in school and when to provide the cultural model to the elders within the family.

THE CHILD AS A SCIENTIST

Think about children as being young scientists. By simply watching a child playing in the sandbox or having fun on a swing set or monkey bars, we see the child making observations and generalizing about matter, momentum, energy transfer, and the properties of objects. They may not realize it, but they are actually using science process skills and testing their ideas while playing.

Science process skills are the *investigative tools* for inquiry. The scientist uses process skills, such as observing, measuring, predicting, inferring, classifying, experimenting, and communicating, to make sense of a new experience, collect evidence to form an explanation, and connect that new explanation to previously held knowledge, conceptions, and models. Other science process skills include controlling variables, collecting data, interpreting data, graphing, model building, using numbers and time-space relationships, estimating, and sequencing. Although we generally describe science process skills as separate skills, they rarely function individually. For example, when scientists make inferences, those inferences are based on observations. In other words, they use observations to draw conclusions and make inferences.

All children are scientists. They use the same process skills as scientists do but on a simpler level. When children observe, they use their five senses—seeing, hearing, smelling, tasting, and touching—to collect data about the things around them. Scientists also make observations as part of their work. However, they use more sophisticated instruments and equipment to extend their senses to gather data, read X rays, or view microscopic organisms. Both the child and the scientist make observations to collect significant information of objects and phenomena surrounding them.

In the same way, we also use observations for other critical thinking skills, such as comparing and contrasting and finding patterns in nature. We use observations and data to make predictions about future events. The better our observations are, the more confidence we have in our predictions. Teachers also know that as soon as a young child makes a new observation in class, communication soon follows. Before they know it, the child wants to tell everyone in the class about the discovery!

TEACHING SCIENCE THROUGH INQUIRY

We have now seen that learning science is an ongoing process of conceptual change and modifying our understanding. Similar to the way scientists continue to modify their models and theories, learning is a continuous, active process. For many of us, inquiry is the perfect vehicle for facilitating a cognitive-based, constructivist approach to learning. In an inquiry/constructivist approach, the learner is engaged in a hands-on science-related question, problem, or investigation. During an inquiry investigation, the child observes, questions, and gathers evidence to test his or her present understanding, forming an explanation that constructs meaning for new scientific knowledge.

We have also come to see that inquiry takes time. I often say that to cook inquiry, you need a Crock-Pot, not a microwave. Allowing sufficient time for students to raise and investigate their own questions requires significantly more time than direct teaching strategies. In creating inquiry-based classrooms, we need to plan our instructional plans carefully so that time is allotted for students to act as scientists and explore their interests. In becoming inquiry-based teachers, we also need to find the time to develop our own capacities to teach through inquiry and constructivist strategies. You have already taken one more step in the commitment to develop an inquiry-centered classroom. I hope you are ready to hang a sign on your classroom door that invites your students to *Inquire Within.*

4

Designing Inquiry-Based Classrooms

Imagine a typical Monday morning in a typical American school—call it John Glenn Middle School. As you walk down the hall and peer into a classroom, how would you know if you were just about to enter an inquiry-centered room? What would the students be doing? What would the teacher be doing? What would the physical arrangement of the classroom look like? What would you see on the classroom walls and on the bulletin boards? Most inquiry classrooms look and feel differently than typical traditional classrooms. Inquiry classrooms are usually designed to be child centered and interactive. In this chapter, we begin to understand the differences between traditional and inquiry-centered classrooms.

TRADITIONAL AND INQUIRY-CENTERED CLASSROOMS

Now, imagine yourself entering a science class in that typical school. (Teacher and student names are fictitious.) Mr. Fenwick has been teaching at the school since 1969. Today, his lesson is "heat as a source of energy." His desk and an overhead projector are centered in the front of the room. The students' desks are lined up in straight rows. Mr. Fenwick believes that knowing science means understanding the vocabulary that explains science concepts. He usually provides lectures with notes for students to copy from the overhead projector. During this particular class, students are reading aloud from the textbook, one at a time, as Mr. Fenwick stands alongside his desk. Following the reading assignment, Mr. Fenwick tells the students to turn to the back of the chapter and answer the review questions.

Ms. Jackson's room is down the hall. She is in her sixth year of teaching. She has just completed her master's degree and has considerable graduate-level course work in inquiry-based teaching. In this classroom, Ms. Jackson's desk is at the side of the room. There is a portable worktable in the front corner that both the teacher and students occasionally share. The student desks are arranged in groups. Each group has four student desks facing each other. There are six groups of students' desks. Ms. Jackson is also presenting a lesson on heat. In this lesson, students work in groups, rotating from station to station and completing an investigation at each station. As you look around the room, Ms. Jackson moves from group to group helping students function as independent learners. She also stimulates their thinking skills by posing questions that encourage them to analyze and make judgments about their work.

BUILDING A DEFINITION FOR AN INQUIRY-CENTERED CLASSROOM

Keeping the contrasting classrooms in mind, visualize an inquiry-centered classroom and identify what the teacher and students would be doing. Using the graphic organizer shown in Figure 4.1 (at the end of this chapter), begin to identify the characteristics of an inquiry classroom. On your graphic organizer, describe the student's role. You may list statements such as "asking questions," "making observations," "working in cooperative groups," "designing procedures to test a hypothesis," or "sharing ideas with others." When characterizing the teacher's role, typical statements might include "posing questions to students," "acting as a facilitator of learning," or "exploring interests of the students." You may have depicted the environment as "interactive and engaging" with indicators such as "students' desks are arranged in groups," or "students' work is displayed on walls and bulletin boards."

The following sections provide a background for observing each of these three aspects of the classroom. At the end of this chapter, you will go back to your graphic organizer and make accommodations and changes to your understanding of an inquiry-centered classroom.

STUDENTS IN INQUIRY-CENTERED CLASSROOMS

Because the role of the student is at the center of inquiry-based learning, it is appropriate to begin our discussion with student behaviors that characterize inquiry. When observing students doing inquiry, we generally observe the following kinds of behaviors:

1. Students are acting as researchers and investigators.
2. Students are taking responsibility for their own learning.
3. Students are working in groups.
4. Students are using higher-order thinking skills.
5. Students are showing an interest in science.
6. Students are making decisions as to how to communicate their work.
7. Students are demonstrating their science understandings and abilities in a variety of forms.

In 1991, NETWORK, Inc. (Andover, Massachusetts) received a grant from the National Science Foundation to support inquiry-based learning. The project, titled Vermont Elementary Science Project (VESP), was located at Trinity College in Burlington, Vermont. Participants of VESP discussed the actions of students engaged in inquiry science. As a result of that discussion, they created the *On the Run Reference Guide to the Nature of Elementary Science for the Student*. According to VESP[1], "the intent is not to use the guide as a checklist, but as a statement of what we value in the area of science processes, science dispositions, and science development. We urge you to capture evidence of your own students engaging in these indicators." VESP suggests that "when students are doing inquiry-based science, an observer will see" the following:

Students View Themselves as Scientists in the Process of Learning

1. They look forward to doing science.
2. They demonstrate a desire to know more.
3. They seek to collaborate and work in cooperative groups with their peers.
4. They are confident in doing science; they demonstrate a willingness to modify ideas, take risks, and display healthy skepticism.
5. They respect individuals and differing points of view.

Students Accept an "Invitation to Learn" and Readily Engage in the Exploration Process

1. Students exhibit curiosity and ponder observations.
2. They take the opportunity and time to try out and persevere with their own ideas.

Students Plan and Carry Out Investigations

1. Students design a fair test as a way to try out their ideas, not expecting to be told what to do.
2. They plan ways to verify, extend, or discard ideas.
3. They carry out investigations by handling materials with care, observing, measuring, and recording data.

Students Communicate Using a Variety of Methods

1. Children express ideas in a variety of ways: journals, reporting about, drawing, graphing, charting, etc.
2. They listen, speak, and write about science with parents, teachers, and peers.
3. They use the language of the processes of science.
4. They communicate their level of understanding of concepts that they have developed to date.

Students Propose Explanations and Solutions and Build a Store of Concepts

1. Students offer explanations from a "store" of previous experience and from knowledge gained as a result of ongoing investigation.
2. They use investigations to satisfy their own questions.
3. They sort out information and decide what is important (what does and doesn't work).

4. They are willing to revise explanations and consider new ideas as they gain new knowledge (build understanding).

Students Raise Questions

1. Students ask questions (verbally or through actions).
2. They use questions to lead them to investigations that generate or refine further questions and ideas.
3. Students value and enjoy asking questions as an important part of science.

Students Use Observations

1. Students observe carefully, as opposed to just looking.
2. They see details, seek patterns, detect sequences and events; they notice change, similarities, and differences.
3. They make connections to previously held ideas.

Students Critique Their Science Practices

1. They create and use indicators to assess their own work.
2. They report and celebrate their strengths and identify what they'd like to improve upon.
3. They reflect with adults and their peers.

STUDENTS ACTING AS RESEARCHERS

Curiosity and imagination are at the heart of inquiry. They pump questions through the learner. When students act as researchers in inquiry classrooms, they take on new roles. Acting as researchers leads students to using integrated process skills such as identifying variables, writing hypotheses, designing experiments and investigations, constructing data tables and graphs, and analyzing the relationships between variables.

Having students act as researchers is a challenging endeavor for both students and teachers. For students to take on new roles, teachers must assume new roles as well. Teachers must believe that students have the skills and interest to carry out their own investigations and generate their own ideas. When students act as researchers and are given the opportunity to raise questions of their own choice on a topic, they start taking responsibility for their own learning. Many students prefer to solve their own questions rather than answer someone else's. As researchers, students can make decisions about their own work, such as how they will collect and organize data and how they will communicate their findings to the rest of the class. By planning and designing their inquiries, students begin to use higher-level thinking skills, such as analyzing and evaluating, to guide the design and course of their investigations. Teachers will begin to find that they need to provide less answers and more support to students. A teacher's guidance may include (a) guiding the students to a location to search the Internet for a particular topic, (b) suggesting that they call a local expert on the topic, or (c) recommending primary sources for the students to review.

According to the *National Science Education Standards* (*NSES*) (NRC, 1996), in challenging students to accept and share responsibility for their work,

> teachers [should] make it clear that each student must take responsibility for his or her work. Teachers also create opportunities for their own learning, individually and as members of groups. Teachers do so by supporting student ideas and questions and by encouraging students to pursue them. Teachers give individual students active roles in the design and implementation of investigations, in the work with their peers, and in student assessment of their own work. (p. 36)

STUDENTS WORKING IN GROUPS

According to the AAAS (1990),

> the collaborative nature of science and technological work should be strongly reinforced by frequent group activity in the classroom. Scientists and engineers work mostly in groups and less often as isolated investigators. Similarly, students should gain experience sharing responsibility for learning with each other. (p. 202)

In many instances, students should work individually; at other times, collaborative group work is more appropriate. This decision is often made according to the teacher's discretion, depending on the objective and nature of the lesson being studied. Group work can allow the members to learn from each other, share and challenge their ideas, and distribute the work in an equitable fashion. Students learn to construct knowledge together and build positive peer relationships. Group work also allows students to build self-confidence while working collaboratively in a group to complete a common goal. Having students work in groups, however, always requires consideration for gender and cultural equity, as well as the interests, needs, and abilities of the group members.

According to Adams and Hamm (1998),

> cooperative learning is more than having students cooperate in a group activity or project. There is a set of strategies that encourage student cooperation while learning in a variety of settings, disciplines, and different grade levels. The process involves promoting positive interdependence by dividing the workload, providing joint rewards, holding individuals accountable, and getting students actively involved in helping each other master the topic being studied. Creative social engagement is paramount. (p. 2)

In both elementary and middle school settings, group work often becomes louder than traditional *seat-time* work. Because students are expected to communicate, debate, and move about the room while working in groups, classroom management techniques become essential. Students need and want rules of conduct to be established. They want to know the limits of classroom behavior. Problems often occur in the inquiry classrooms when the teacher fails to effectively communicate the expectations for group work. The teacher can enhance expectations and rules for appropriate behavior by having students participate in deciding what rules need to be enforced while doing a scientific investigation. The student can agree to the rules and post them in the classroom. Classes can consider adopting rules of conduct by citing the positive behaviors that are expected (starting with the word *Do*) rather than rules written in a negative tone (starting with the word *Don't*).

STUDENTS USING HIGHER-LEVEL THINKING SKILLS

In a community of inquirers, using exploration and discourse strategies stimulates students to think critically about the data and evidence accumulated during their inquiry. This motivates students to analyze and synthesize the data and to make judgments and evaluations about the results and conclusions. These types of thinking skills are far superior in developing scientific literacy to the kinds of questions repeatedly posed to students in traditional classrooms, in which the recall of science fact is valued. In contrast, as students experience inquiry investigations, they use thinking skills that cause them to reflect about their work and pose logical arguments to defend their conclusions.

At the primary level, thinking skills in inquiry involve having the students focus on generating questions and on making sense of their ideas. At the intermediate level, students are beginning to make the transition into higher-level concrete operations and are more likely to understand the relationships between their prior knowledge and their new experiences. Secondary students are better equipped to see cause-and-effect relationships, formulate hypotheses, interpret and draw conclusions, evaluate relationships between variables, and use two- and three-dimensional models to explain their conclusions (Hester, 1994). At the start of high school, many students begin to make the transition from concrete operations to formal levels of operations and thinking more abstractly.

STUDENTS SHOWING INTEREST IN SCIENCE

"Why do we have to learn this stuff anyway?" one eighth-grade girl asked. "Because," the teacher responded, "you have to know it when you get to high school." Have you been asked that question before? It seems every teacher has been asked that question at sometime in his or her career. From the point of view of the student, what does the question mean? Does it mean she doesn't like science? Does it mean she doesn't like this particular lesson? Or does it mean she doesn't understand what she is expected to do? All we know at this point is that the student might not see the relevance of the content she is expected to learn.

Posing problems of importance and relevance to students is an integral aspect of inquiry and constructivist teaching (Brooks & Brooks, 1993). That does not mean that in inquiry classrooms the students decide what and when they want to learn. Nor does it mean that teachers must wait until the students want to learn about Newtonian physics before the subject can be presented. It does mean, however, that in inquiry classrooms the teacher mediates relevance by engaging students in meaningful problem-solving investigations. According to Brooks and Brooks (1993), "The inquiring teacher mediates the classroom environment in accordance with both the primary concept she has chosen for the class's inquiry and her growing understanding of students' emerging interests and cognitive abilities within the concept" (p. 38). Making learning meaningful is another central theme in inquiry-based learning. Brooks and Brooks go on to say,

> It's unfortunate that much of what we seek to teach our students is of little interest to them at that particular point in their lives. Curriculums and syllabi developed by publishers or state-level specialists are based on adult notions of what students of different ages need to know. Even when the topics are of interest to students, the recommended methodologies for teaching the topics sometimes are not. Little wonder, then, why more of those magnificent moments don't occur. (p. 106)

In inquiry classrooms, students are engaged in investigations that interest them through prompting and mediation from the teacher. As a result, students demonstrate open-mindedness and curiosity; they also gain an appreciation for and positive attitude toward science. Seeing themselves working as researchers and scientists does much to promote interest in science and encourages students to pursue further science courses in the years ahead.

TEACHERS IN AN INQUIRY-CENTERED CLASSROOM

The teacher's behavior and competency are paramount in inquiry classrooms. They set the stage for teaching and learning. When observing inquiry-based teachers, we often see a different style of presentation, organization, questioning skills, and even body language than in traditional settings. The following is a list of behaviors that often accompany good teaching as well as inquiry-based learning. In inquiry classrooms, we often see teachers behaving as follows:

1. Choosing topics to study on the basis of national standards
2. Limiting the use of lecture and direct instruction to times when the lesson cannot be taught through hands-on or inquiry-based instruction
3. Being focused yet flexible by having preplanned lessons and questions while mediating the lesson to follow the direction of the students' questions
4. Assessing prior knowledge before starting a lesson or unit of study and using students' prior knowledge as a basis for introducing new concepts
5. Listening to students' comments and becoming aware of their misconceptions
6. Making learning meaningful by exploring student interests, taking student interests into account, and basing lessons on students' prior suppositions
7. Using investigations to anchor new information to previous knowledge
8. Initiating classroom discussion and discourse by asking starter questions, prompts, and posing thought-provoking questions throughout the lesson
9. Asking questions that require critical thinking skills
10. Using *wait-time* appropriately rather than interrupting students in the middle of their questions and answers
11. Posing prompts and clarifying and rephrasing student questions and responses rather than divulging answers, so that students can begin to answer their own questions
12. Saying "Thank-you" for student contributions and giving positive reinforcement for their contributions and good work in cooperative groups
13. Asking follow-up questions to student answers rather than saying "Okay" or repeating the student answer

14. Maintaining appropriate classroom management during hands-on investigations by displaying rules in a positive way, providing expectations, structure, and creating a safe and well-organized room
15. Establishing everyday routines for group interaction and for getting and returning materials
16. Arranging students' seats to work in groups
17. Focusing the lesson on engaging, relevant, and problem-solving situations
18. Moving about the classroom and rotating to each small group
19. Encouraging students to construct their own investigations
20. Kneeling to make on-level, eye-to-eye contact when speaking to students in small group settings
21. Valuing student responses
22. Keeping students on task by having them support their findings by debating, challenging, and questioning their conclusions
23. Using time efficiently
24. Integrating science content with process skills and problem-solving strategies as well as mathematics, technology, and other subjects
25. Acting as a facilitator, mediator, initiator, and coach while modeling the behaviors of inquiry, curiosity, and wonder
26. Using primary sources of information rather than textbooks
27. Using resources from inside and outside the school setting
28. Encouraging communication skills such as speaking and listening
29. Encouraging students to use concept mapping and drawing models to explain and demonstrate newly acquired knowledge
30. Assessing student performance in a variety of forms and monitoring student progress continuously on a day-to-day basis
31. Helping students assess their own progress

AN INQUIRY-CENTERED CLASSROOM

As we begin to see, the inquiry classroom environment is somewhat different from traditional settings. To begin with, inquiry classrooms are often described as learner centered and interactive. That doesn't mean traditional classrooms are not child or learner centered. For the purpose of building a definition of an inquiry classroom, start by asking yourself, how would you know if you'd walked into a classroom where the students learn through inquiry strategies? What would the classroom look like? How would it be arranged? Would you expect to see the desks arranged in straight rows? Where would the teacher's desk be located? How would that classroom be different from a traditional classroom?

You may want to begin to answer those questions by designing an inquiry-based classroom of your own. On a separate sheet of paper, design a room for the number of students in your classroom. Place the teacher desk, the student desks, and *learning centers* in any way that complements an inquiry classroom.

Although not all inquiry classrooms look the same, there are some common things to look for. In inquiry-based classrooms we often see

1. "What if" and "I wonder" questions posted throughout the room
2. Concept maps displayed on the walls

3. Evidence of student work throughout the room
4. Students' desks arranged in groups of two, three, or four
5. Expectations for student behavior posted
6. Learning centers for individual and small-group work
7. Fiction and nonfiction books, magazines, and resources on the shelves
8. The teacher's desk at the side or back of the room rather than front center
9. A box or crate for student portfolios and journals
10. Materials and supplies readily available in bins or containers
11. Areas set aside for storing projects and investigations in progress
12. Videotaping equipment available for recording student presentations and reflecting on and analyzing their performances
13. Computers available for accessing information beyond the school building

How were these descriptors similar to what you designed in your inquiry-based classroom? Because of the increased student movement, teachers must pay specific attention to traffic patterns. Making the place safe and organized is an important consideration when designing the room.

In the beginning of the school year, when students arrive for the first time, the room is traditionally set up for them in advance by the teacher. As the year goes on, the teacher may offer students the opportunity to rearrange the room according to their own design. This makes the room truly "their room" and adds a personal touch to the environment. To support this notion, the *NSES* (NRC, 1996) says,

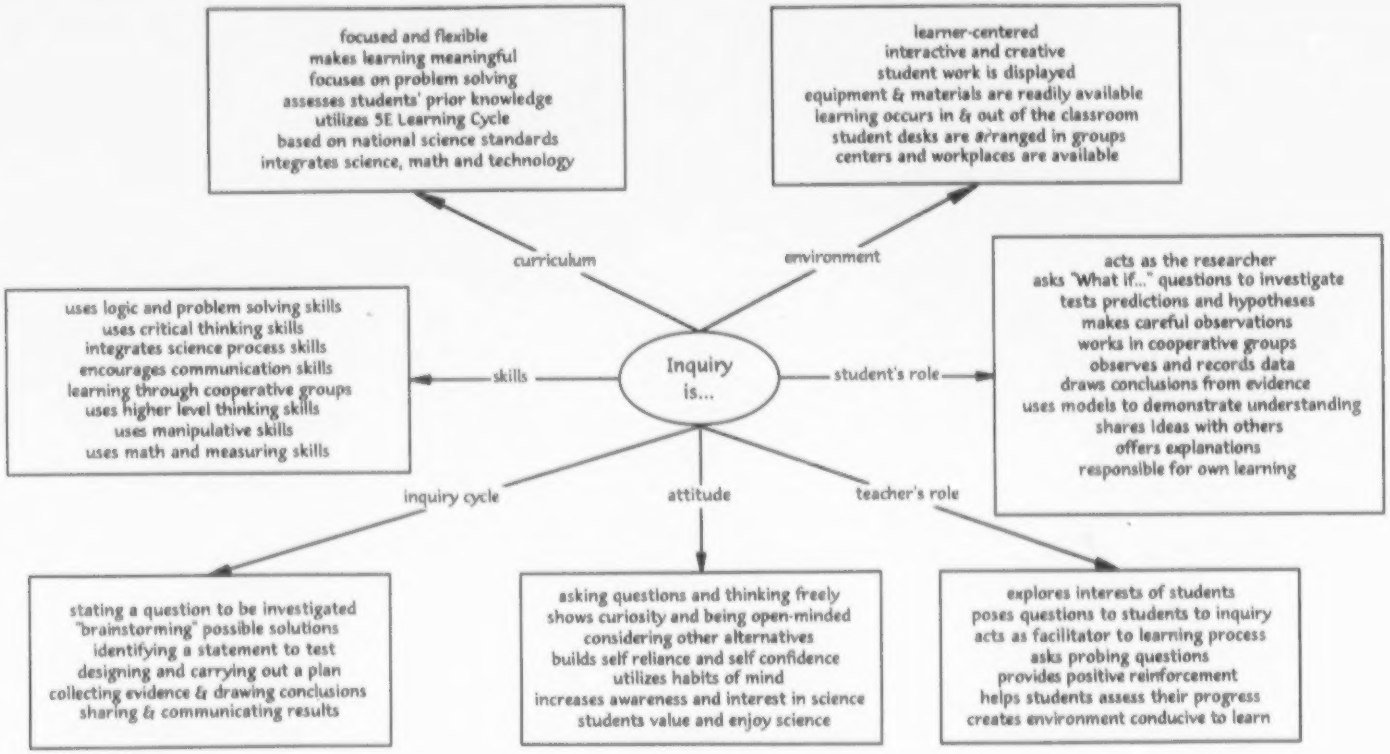
> The arrangement of available space and furnishings in the classroom or laboratory influences the nature of the learning that takes place . . . [and] schools must restructure schedules so that teachers can use blocks of time, interdisciplinary strategies, and field experiences to give students opportunities to engage in serious scientific investigation as an integral part of their science learning. (p. 44)

Now that we have completed the first four chapters, go back to the statements or concept maps you made in Chapters 1, 2, and 3. Make any modifications or additions. Figure 4.1 is an example of a teacher using a graphic organizer to separate her statements on inquiry into seven different subtopics: curriculum, environment, student's role, teacher's role, attitude, inquiry cycle, and skills.

NOTE

1. The following material is from the Vermont Elementary Science Project. *On the Run Reference Guide to the Nature of Elementary Science for the Student* (p. 13). Burlington, VT: Trinity College. © 1991 by the Vermont Elementary Science Project, Trinity College, McAuley Hall, Burlington, VT 05401. (802) 658-3664. Used with permission.

Figure 4.1. What Is Inquiry?



focused and flexible
makes learning meaningful
focuses on problem solving
assesses students' prior knowledge
utilizes 5E Learning Cycle
based on national science standards
integrates science, math and technology
learner-centered
interactive and creative
student work is displayed
equipment & materials are readily available
learning occurs in & out of the classroom
student desks are arranged in groups
centers and workplaces are available
curriculum
environment
acts as the researcher
asks "What if..." questions to investigate
tests predictions and hypotheses
makes careful observations
works in cooperative groups
observes and records data
draws conclusions from evidence
uses models to demonstrate understanding
shares ideas with others
offers explanations
responsible for own learning
uses logic and problem solving skills
uses critical thinking skills
integrates science process skills
encourages communication skills
learning through cooperative groups
uses higher level thinking skills
uses manipulative skills
uses math and measuring skills
skills
Inquiry is...
student's role
inquiry cycle
attitude
teacher's role
stating a question to be investigated
"brainstorming" possible solutions
identifying a statement to test
designing and carrying out a plan
collecting evidence & drawing conclusions
sharing & communicating results
asking questions and thinking freely
shows curiosity and being open-minded
considering other alternatives
builds self reliance and self confidence
utilizes habits of mind
increases awareness and interest in science
students value and enjoy science
explores interests of students
poses questions to students to inquiry
acts as facilitator to learning process
asks probing questions
provides positive reinforcement
helps students assess their progress
creates environment conducive to learn

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5

Integrating Inquiry-Based Activities

PROMOTING STUDENT INQUIRIES

By now, you should have a good idea of what inquiry-based classrooms look like. We can now focus on describing the activities that take place in those classrooms. This chapter will help you distinguish between typical science activities and those that encourage students to raise questions and pursue the answers to their own questions.

Teachers getting started in inquiry usually ask two questions: "What are inquiry activities?" and "How do I get my students started in inquiry activities?" These two basic questions are essential for any teacher beginning a journey into developing an inquiry-centered classroom. This chapter will answer both of them.

Starting in the primary grades, children seem to display a natural curiosity about science and like asking questions. Edwards (1998) says,

> Young children seem to have a never-ending supply of questions. Older children, on the other hand, rarely ask questions, preferring instead to let their teachers perform this duty. They are accustomed to providing memorized answers to questions asked by the teachers. It can be safely said that this behavior is shaped by the educational system. The consequence of this conditioning process is well established in most learners once they have spent a few years in school and can significantly interfere with their ability to formulate questions and conduct self-directed investigations. Teachers interested in promoting inquiry have a challenging task to overcome the tendency of many older students to become passive. (pp. 18-20)

At the secondary school level, teachers daily face prepubescent and "budding" adolescents whose bodies are filled with roller-coaster hormones and emotions. Middle and high

Figure 5.1. Invitation to Inquiry Grid

	Demonstrations	*Activity*	*Teacher-Initiated Inquiry*	*Student-Initiated Inquiry*
Posing the Question	Teacher	Teacher	Teacher	Student
Planning the Procedure	Teacher	Teacher	Student	Student
Formulating the Results	Teacher	Student	Student	Student

school students are often self-conscious about raising questions and appearing to "stand out" in the class. For this reason, secondary school science teachers who have students with little prior experience in inquiry should gradually introduce their classes to student-initiated investigations. The "Invitation to Inquiry Grid" (Llewellyn, 1998) serves as a way to identify inquiry-based investigations and help guide more traditional students into thinking and acting like researchers.

INVITATION TO INQUIRY

The experiments and activities we do in science can be divided into three basic and separate sections:

1. Posing the question
2. Planning the procedure
3. Formulating the results

We can picture the teacher, in one scenario, posing a question to his or her students. We can picture the teacher describing how the procedure of the experiment will take place and actually doing the steps. We can also imagine the teacher providing the results of the experiment and then formulating the conclusions. We call this scenario a *demonstration*. In a second situation, the teacher poses the question to the students and provides a procedure for answering the question. The students follow the procedure and formulate their own results. We call this an *activity*. In a third situation, the teacher poses the question to the students and invites the students to plan the procedure and formulate the results. We call this a *teacher-initiated inquiry*. In our final situation, the students pose a question, plan a procedure for answering the question, carry out the procedure, and formulate the results. We call this a *student-initiated inquiry*.

Figure 5.1 summarizes the four stages of instruction. Each stage serves as a vehicle to invite student-initiated questions and student-directed procedures that will transport students to an inquiry level.

DEMONSTRATIONS

According to the "Invitation to Inquiry Grid" (Llewellyn, 1998), demonstrations focus the attention and the control of the entire instructional situation on the teacher. Many teachers are very familiar with doing demonstrations because they play an important role in teaching science. Some topics in science are best presented through demonstrations. Demonstrations also give teachers an opportunity to be the center of attention: to be a "Bill Nye the Science Guy" or a "Mr." or "Ms. Wizard." For the teacher, doing demonstrations captures the attention of the audience. For the students, demonstrations can be interesting and enjoyable to watch.

Why do teachers do demonstrations? There are several excellent reasons for doing so:

- All students need to observe a particular phenomenon.
- The procedure is complicated for students to follow.
- The results of the situation need to be controlled.
- Dangerous, toxic, or flammable materials are used.
- An explosion may (or will) result.
- Safety is a concern.
- Materials or equipment are limited.
- Expensive chemicals or supplies are being used.
- Time is of the essence.

You can probably think of many other reasons to do demonstrations. Traditional demonstrations are usually done to show students a particular phenomenon. When a demonstration results in an observation or conclusion that is counterintuitive to a student's normal experience, the demonstration evokes "What if" or "I wonder" questions. Demonstrations that invite further inquiry are often called *discrepant events*.

DISCREPANT EVENTS

Discrepant events are mind-engaging demonstrations or activities in which students observe unexpected results that are contradictory to their normal or anticipated experiences. Wondering why these unexpected things happen provides students with the motivation and interest to formulate questions to pursue. Discrepant events are especially useful for starting a lesson or a unit, capturing a student's interest, and promoting curiosity. Teachers often create low-cost discrepant events, using everyday household items, to introduce scientific concepts.

Observing a discrepant-event demonstration can serve as a springboard to science inquiry. Rather than introducing a new topic or concept and later providing a demonstration to prove that the concept is correct, a teacher can use a discrepant event in the beginning of the lesson to capture the students' imagination and sense of wonder. Discrepant events are used successfully when they initiate a *wanting to know*. Several steps are recommended in incorporating discrepant events into a lesson:

1. Demonstrate the event. Present students with an opportunity to observe results that contradict their normal expectancy. Provide students with an opportunity to confront the questions being raised.

2. Prompt students to investigate the event. Students should be encouraged to test the event or discrepancy by using science process skills such as observing, inferring, recording data, formulating hypotheses, and generalizing. Allow sufficient time to test the event and form hypotheses or questions. Encourage students to raise "What if" and "I wonder" questions about the discrepancy. Provide guidance while introducing inquiry strategies without giving away the answer or explanation.
3. Allow time for students to test their "What if" and "I wonder" questions and share the results of their inquiries.
4. Discuss the causes of the discrepancy while introducing the topic being studied (density, pressure, heat, etc.). During the discussion, refer back to the demonstration to *personalize* the concept being presented.
5. Apply the concept being studied to an application level beyond the classroom. Provide a culminating activity or laboratory experience that extends the learning rather than proving what was already said is correct.

For a comprehensive resource on discrepant events, see *Invitations to Science Inquiry* in Resource A.

"HAPPY AND UNHAPPY BALLS"

An example of a discrepant event that has been frequently used in elementary- and secondary-level science classes is titled "Happy and Unhappy Balls," available from Edmund Scientific (Barrington, New Jersey) or Arbor Scientific (Ann Arbor, Michigan). The following lesson was adapted from the Edmund Scientific data sheet for "Happy and Unhappy Balls."

The teacher begins the class by showing students what appear to be two identical black balls and leads a discussion on how to design a way to determine which ball will bounce the highest when dropped. (Although identical in appearance, the balls are made of two different types of rubber.) To determine a fair experiment, students may suggest controlling variables such as the height from which the ball is dropped, the surface the balls are dropped on, and how the balls are released (with no additional effort when releasing). After exploring all the variables and designing the experiment, the balls are released. The results add a strange twist to the test. One ball bounces, but the other drops directly to the surface of the table without bouncing.

Following the demonstration, students are amazed by the results. Many may suggest repeating the procedure, and others may think it's a trick. Some may wonder what would happen to the two balls if they were rolled down an inclined plane, and still others may wonder if the temperature of each ball might affect the height it would reach. In any case, good demonstrations lead students to think critically and raise more questions to investigate.

ACTIVITIES

In traditional hands-on activities, the teacher provides the question to be studied or tested. The question is usually provided for students at the top of the activity or lab sheet. The students are also told what materials to use and what procedures to follow to generate data and results. These activities are sometimes called *cookbook* science because, like a cook following a recipe in a book, students are expected to follow prescribed directions or procedures that produce results that are predictably the same. Many teachers subscribe to this type of *confirmation activity* because it provides direction for the students and tells them what to do to complete the experiment. Most of the "experiments" found in textbooks fall into this category.

Teachers often "stick to what's in the textbook" and rely on prescribed activities as their sources for involving students in science; they feel that such activities are easy to follow and provide students with focus and direction in carrying out the activity. Although activities do provide students with an opportunity to do hands-on, manipulative science, it is the teacher's role to promote and encourage further questions and pursue self-directed investigations—the goal of inquiry-based learning. The purpose of cookbook activities is to confirm what is already known.

Activities can become a means of inviting inquiry—a kind of springboard into inquiry. Like discrepant events, they provide opportunities for students to make observations or discoveries that are unexpected or unpredicted. In the "Inquiring With Fruit" activity cited in Chapter 1, the teacher provided the question to study. The teacher also provided the procedures for directing students to make their own predictions. Whether a particular fruit floated or sank spurred the students to raise "What if" or "I wonder" questions.

Providing *extension* or *going-further* questions at the end of an activity is another way to engage students. For example, in a traditional activity, the teacher poses the following question: "How do the dissolving rates differ between a sugar cube and granulated sugar?"

Then, the teacher provides the following materials to be used:

- Two empty 250-ml beakers
- One 500-ml beaker of room temperature water
- One sugar cube
- One packet of granulated sugar
- One stopwatch

Next, the teacher provides the following procedures for the students:

1. Fill one 250-ml beaker with 125 ml of water.
2. Place the sugar cube in the 250-ml beaker with water.
3. Use the stopwatch to record the time it takes for the tablet to dissolve.
4. Record the time in the data table.
5. Fill the second 250-ml beaker with 125 ml of water.
6. Pour the granulated sugar from the packet into the second 250-ml beaker.
7. Use the stopwatch to record the time it takes for the sugar to dissolve.
8. Record the time in the data table.

Although this is a relatively simple activity that most students can complete, you can see how teacher directed it is. The original question and procedures are all provided to the students. All the students have to do is follow the steps of the procedure and record the time in the appropriate column in the data table. You can see that this activity can be thought of as a type of cookbook activity, and although it is hands-on, it is not inquiry based.

One step toward incorporating inquiry into the lesson would be to have several prearranged extension questions for students to investigate on their own. The teacher could pose several questions to investigate, but on the basis of their knowledge from the original activity, the students would be expected to write their own procedures and carry out their own investigations. Several preplanned or extension questions could include the following:

How does stirring the water affect the dissolving rate?
How does the temperature of the water affect the dissolving rate?
How does the amount of water in the beaker affect the dissolving rate?
Does granulated brown sugar dissolve differently than white sugar?
Do solid antacid tablets dissolve faster or more slowly than powdered antacids?
Does adding food coloring to the water affect the dissolving rate?
How can you make a sugar cube dissolve in the shortest amount of time?

In this way, a simple traditional activity can be extended into an inquiry lesson.

TEACHER-INITIATED INQUIRIES

In teacher-initiated inquiries, sometimes called *guided inquiry,* the teacher poses the original question and then allows time for the students to consider possible solutions, plan an investigation, and go about answering the question posed to them. Teacher-initiated inquiries work well when students are not accustomed to solving problems and initiating questions on their own. This is especially true at the beginning of the school year.

Another teacher-initiated inquiry that is especially good for elementary and middle school students is called "Pumpkin Math & Science." Students are given the starter question, "How can you find the volume of a pumpkin?" They begin by brainstorming ways to measure the pumpkin. Some may measure the height by cutting a hole in the center of a piece of cardboard and placing the cardboard over the stem of the pumpkin. While holding the cardboard parallel to the surface of the tabletop, students could use a ruler to measure the height of the pumpkin and determine who has the tallest pumpkin. Others may want to measure the "fatness" or circumference of the pumpkin, using a string or belt from their pants to measure the distance around the pumpkin. Students may also suggest that a water displacement method is really the best means of determining the pumpkin's volume. To accomplish this, a student might suggest using the classroom wastebasket filled to the top with water. Another might suggest using a dishpan to catch the water that spilled over as the pumpkin was pushed completely down into the water. By measuring the water overflow, the students can easily determine the volume of the pumpkin!

After exploring and observing pumpkins firsthand, students can make a list of what they wanted to know about pumpkins. Here are a few questions they may consider:

How thick is the shell of the pumpkin?
Do all pumpkins have the same number of "grooves" on the outside?
How many seeds are in a pumpkin?
Do all pumpkins have the same number of seeds?
Do bigger pumpkins have more seeds than smaller pumpkins?
How heavy is a pumpkin seed?
Do pumpkinseeds float?
Do pumpkins float?

How can you tell which side of the pumpkin grew down on the ground, and which side was facing up to the sky?
Is a pumpkin a vegetable or a fruit?
What is the weight of the largest pumpkin ever grown?

Pumpkin investigations can last well into mid-November. In fact, you may prefer to start your pumpkin investigations after Halloween. The market value of pumpkins drops significantly after October 31. If you wait until then to ask a storeowner or a farmer for their pumpkins, you will probably get all you'll need—free!

STUDENT-INITIATED INQUIRIES

The highest level of inquiry occurs when students raise and initiate their own questions. According to the "Invitation to Inquiry Grid" (Llewellyn, 1998), in student-initiated inquiries, sometimes called *open inquiry*, students raise their own questions, formulate their own procedures, and determine their own results. In some cases, students may need prompting or an exploration experience to raise questions and engage them in inquiry. The ice hand investigation was an example of a student-initiated inquiry. The ice hands provided the exploration phase for students to make observations and raise questions to investigate. Students generally raise questions on the basis of their prior experiences and from observing discrepancies, so it would have been more difficult for them to think of questions to investigate without the ice hand exploration. In their investigations, students raised and investigated their own questions. This placed them into the student-initiated inquiry category because the questions originated from the students, not the teacher. In other situations, students may raise questions without being prompted or persuaded; however, getting them to develop their own questions may take many guided experiences, especially when dealing with students who have not had prior experience in inquiry-based lessons.

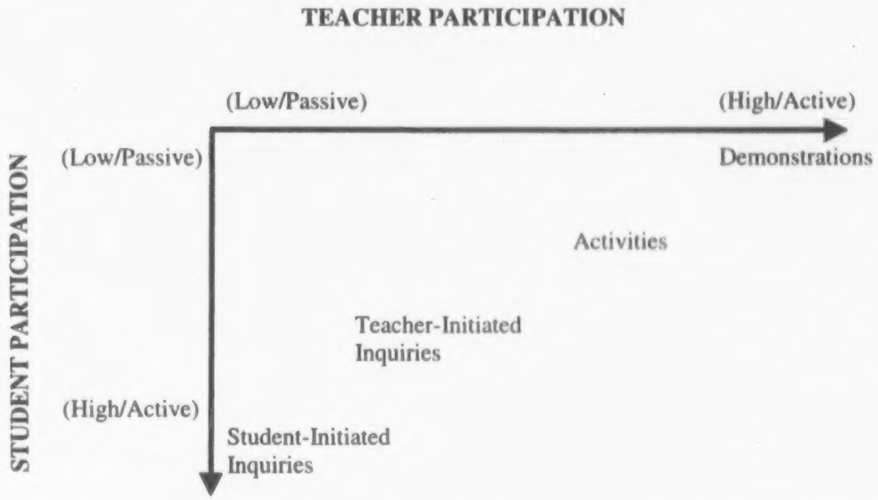
We have seen that the level of self-directed participation and involvement on the part of the teachers and the students varies significantly for each learning situation described. During a demonstration, the teacher plays an active role, and the students are more passive. In contrast, during the student-initiated inquiry, the students are fully engaged, and the teacher plays a less active role. The illustration in Figure 5.2 summarizes the participation level of each learning situation.

GUIDING STUDENTS INTO INQUIRY

Most students (and teachers as well) are not ready to begin with full student inquiries at the beginning of the school year. During the first few weeks of school, teachers need to set expectations for classroom management, discipline, classroom routines, grading procedures, and so on. Establishing and maintaining a healthy and safe classroom is a prerequisite for an inquiry lesson. Without rules, inquiry lessons become unruly and unmanageable. It is normal for teachers to wait until they grow accustomed to their classes before starting a fully inquiry-based unit. This is especially true for teachers who have students coming to them without prior experience in inquiry learning.

For those reasons, the "Invitation to Inquiry Grid" can also serve as a way to plan instructional units so that students are gradually but continuously encouraged to take on

Figure 5.2. Teacher and Student Participation Modes



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more responsibility for their own learning. During the early months of the school year or when students are unfamiliar with inquiry learning, the teacher may choose to begin with the demonstration mode, focusing on having students observe and experience discrepant events. During the next several months, the teacher can then move into the activity stage, concentrating on providing sound hands-on activities that create the opportunity for extension investigations. By midyear, a reasonable expectation would be to have students involved in one or more teacher-initiated inquiries, with the goal of evolving the students' expertise into several fully student-initiated inquiries before the end of the year (see Figure 5.3).

The "Invitation to Inquiry Grid" can also be used as a monitoring tool for teachers in designing their yearlong instructional plans. As the school year proceeds, teachers can ask themselves "Am I moving my students from teacher-dependent to more independent experiences, and am I providing opportunities for student-initiated inquiries as the year goes on?"

By now, you should have a good grasp of the differences between doing hands-on science and inquiry-based investigations. You read that although most inquiry investigations involve hands-on and manipulative means of learning, not all hands-on activities are inquiry based. When a hands-on activity poses a question to the students and also tells the students what materials to use and how to go about finding the answer, it is not inquiry.

A lesson on momentum, using ramps and marbles, is presented in four different ways to further explain the differences between a demonstration, an activity, a teacher-initiated inquiry, and a student-initiated inquiry. Using the same concept, we can then see how each stage differs from one another. Let's suppose we wanted to find out how the height of an inclined plane (a grooved 12-inch ruler) affects the distance a marble travels when allowed to roll down (see Figure 5.4).

Figure 5.3. Inquiry Grid Flowchart

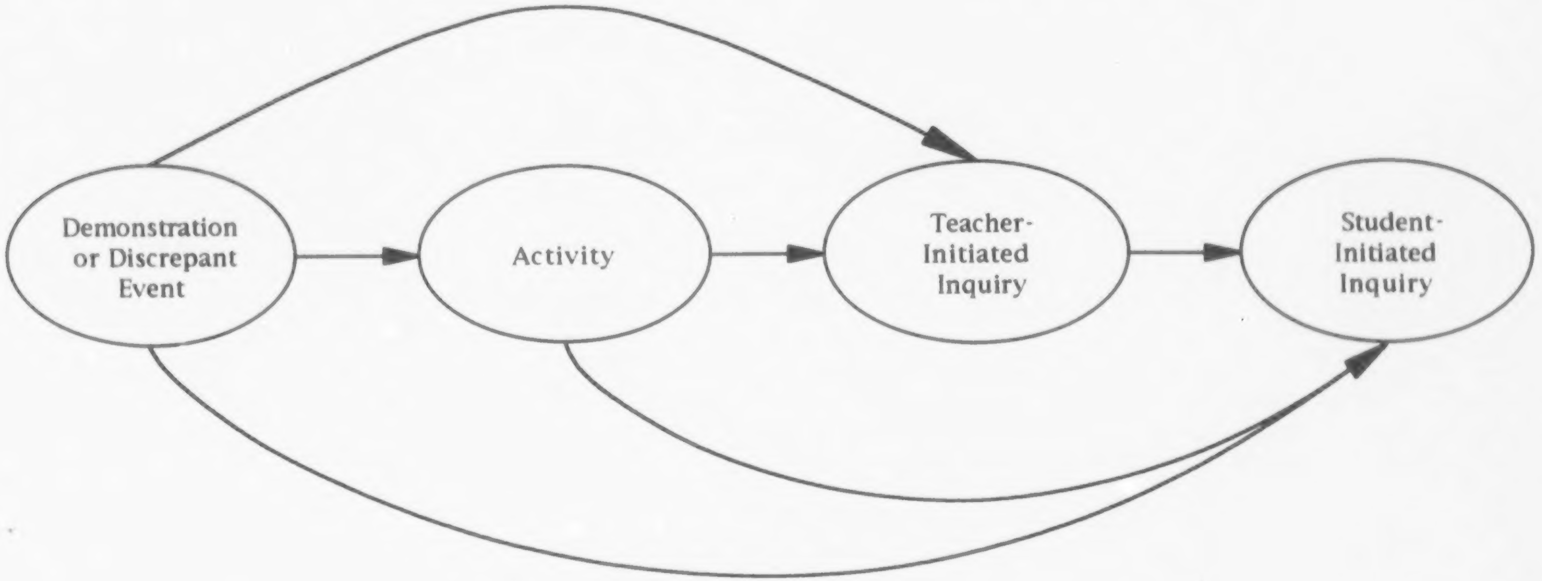
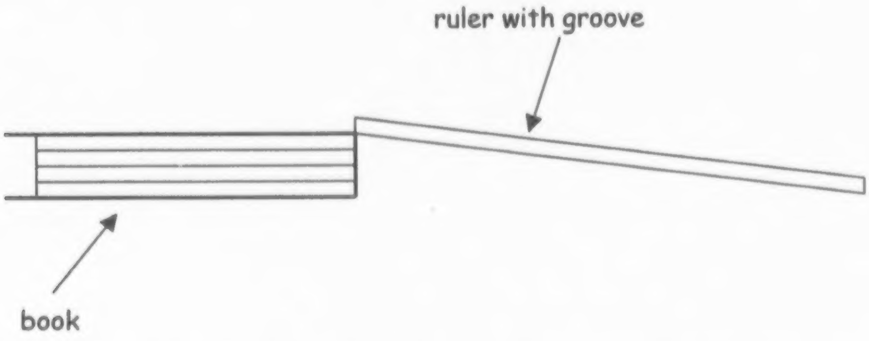

Demonstration or Discrepant Event
Activity
Teacher-Initiated Inquiry
Student-Initiated Inquiry

Figure 5.4. Setup for Rolling Marble Investigation



In a demonstration lesson, the teacher would probably be standing in the front of the class, behind a demonstration table. He or she would pose a question such as "How does the height of an inclined plane affect the distance a marble will travel?" The teacher would then show and describe the supplies and materials to be used in the demonstration.

Following the outlined steps of the procedure, the teacher would set up the materials so that one end of the ruler is elevated 1 inch. The teacher would roll the marble down the groove of the ruler. A student may be called on to act as an assistant during the demonstration, to measure the distance the ball traveled in each of three trials. As the students recorded each distance for the three separate trials on their data sheets, the teacher would explain that the angle of the inclined plane was going to be changed by adding more books to the end of the ruler.

Next, the height of the inclined plane would be increased to 2 inches, with the same procedure followed and data recorded for each trial. The procedure would be repeated for heights of 3, 4, and 5 inches. At the conclusion of the demonstration, the teacher would summarize the data, plot them on a graph, and describe to the students the relationship between the height of the ruler and the distance the marble had rolled. Students might then ask questions about the demonstration.

Because this demonstration does not represent a discrepant event, the teacher may choose to pose going-further or extension-type questions to the class or may end the demonstration without further discussion. The demonstration would probably take 10 to 20 minutes to complete.

In an activity lesson, the teacher would have the students at tables in groups of three or four. A worksheet (see Form 5.1) would be distributed to the groups, and the teacher would provide an overview of the activity and answer any questions about the procedure. The question to be studied would be provided to the students on the activity sheet along with supplies and materials and the steps for following the procedure. The students would be expected to complete the steps and record the distance the marble rolled for each trial.

As the students work on the activity, the teacher would circulate among the groups and provide assistance in answering their questions. In completing this activity, the students would be experiencing a hands-on science lesson with many opportunities to observe, make mathematical measurements, manipulate materials, record data, and draw conclusions. The activity is an excellent way to engage students in doing science. It usually takes 30 to 45 minutes to complete. At the end of the activity, however, the questions posed

FORM 5.1

MARBLE ACTIVITY WORKSHEET

Problem: How does the height of an inclined plane affect the distance a marble will travel?

Hypothesis: The higher the end of the inclined plane, the further the marble will roll.

Materials:
1 12″ ruler with groove
5 books—each 1″ thick
1 marble
1 measuring stick

Procedure:

1. Using the diagram below, place the ruler on the edge of a 1″ book.
2. Place the marble in the groove as far up the ruler as possible.
3. Release the marble.
4. Using the measuring stick, measure the distance (in inches) the marble traveled.
5. Record the result in the data table.
6. Repeat the same procedure for Trials 2 and 3. Release the ruler on the top of the second book so the height of the ruler is now 2″. Repeat the same procedure for 2″.
7. Place a second 1″ book on top of the first book. Place the ruler on the top of the second book so the height of the ruler is now 2″. Repeat the same procedure for 2″. Repeat the same procedure for 3″. Then repeat the same procedure for 4″ and 5″.
8. Use the table below to calculate the average for each slot.

Data table:

Height	Distance marble traveled (inches)			
	Trial #1	Trial #2	Trial #3	Average
1″	____	____	____	____
2″	____	____	____	____
3″	____	____	____	____
4″	____	____	____	____
5″	____	____	____	____

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by the students will determine whether the activity leads into a teacher- or student-initiated inquiry.

For example, suppose the teacher had two different rulers, 12 inches and 18 inches long, and posed the question "How does the length of the inclined plane affect the distance the marble will roll?" Students could then be moved from an activity stage to a teacher-initiated inquiry stage, assuming that the teacher prompted the students to formulate their own procedure to answer the question. On the other hand, suppose a student raised the question, "How does the mass of the marble affect how far the marble will travel?" Then, if the teacher encouraged the students to formulate their own procedure to answer the question, the students would move from an activity to a student-initiated inquiry.

As a teacher-initiated inquiry, the teacher would pose the question "How does the height of the inclined plane affect the distance the marble will roll?" and challenge the students to formulate a procedure to answer the question. The teacher would have different sizes of rulers, some with grooves and some without, various sizes of marbles, of different masses and colors, and measuring tapes available at a supply area. The students would be encouraged to write a hypothesis and a plan to test their prediction. After the plan was completed, the students would be free to get whatever materials they needed to carry out their plan and collect evidence to test their hypothesis.

During this time, the teacher would (a) circulate from group to group and listen in on their discussions, (b) be aware of comments made by the students that revealed any misconceptions about momentum, and (c) provide additional prompts to test their misconceptions. The teacher would pose further questions for the students to consider and have additional inquiries available for those groups who completed their investigations early. For example, one inquiry could involve a steel ball and a glass marble of the same size. The teacher could pose the question "Does the mass of the ball affect the distance the ball will roll?" Depending on the class and the level of their investigations, this inquiry could take from 45 to 60 minutes to complete.

In a student-initiated inquiry, the teacher could assess prior knowledge and uncover misconceptions by asking students to share what they already know about ramps and inclined planes. The teacher might choose to record their experiences by listing them on the board or overhead projector. Next, the teacher would allow time for nondirected experience in which students engage in "messing about" at tables, exploring and observing momentum with balls and ramps. Following this engagement and exploration time, the teacher would encourage students to raise their own personal questions and inquiries about momentum, suggesting that they begin their inquiries with "What if," "I think," or "I wonder."

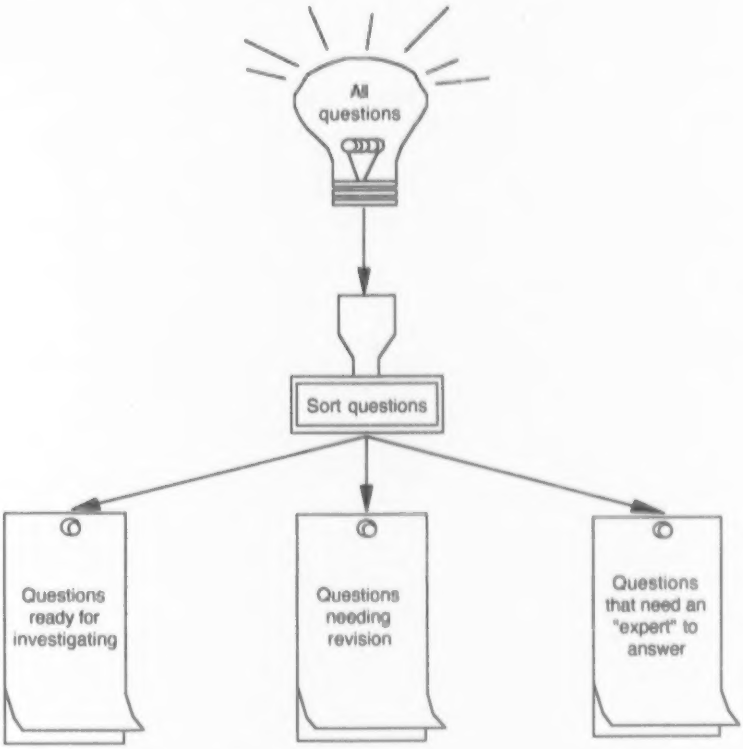
The teacher could again ask the groups to share their questions, while making a list of their questions on the blackboard or overhead project according to the preference of the class. Following this exercise, the teacher would identify each question as

- One that is ready to be answered through an investigation
- One that needs to be revised or rewritten before it can be investigated
- One that requires an outside expert or resource to answer (see Figure 5.5)

It is important for students to classify their questions in these categories to further understand the direction their questions will take them. For example, questions starting with "Why" usually require an explanation to answer. These questions often need to be revised into "What" or "What if" questions before they can be investigated.

Sufficient materials and supplies should be available at a supply center for groups to use as needed. The students can brainstorm ways to solve their questions and go about car-

Figure 5.5. Sorting Students' Questions


All questions
Sort questions
Questions ready for investigating
Questions needing revision
Questions that need an "expert" to answer

rying out their plans. The teacher can rotate from group to group, asking more questions and clarifying students' ideas and prior conceptions about moving objects. The teacher can encourage the groups to write down and investigate other questions that come up during the course of their investigations. At the end of the lesson, the teacher brings all the groups together so they can share their observations and conclusions. Each group is given time to get up in front of the class and state the question it investigated and the results it discovered.

Each of the four levels of instruction has definite advantages and disadvantages, and of course, each teacher can plan and implement the lesson differently from what is described here. By using demonstrations, the time requirement is greatly reduced, and each student is ensured the same opportunity to observe the same concept being studied in the same way. The activity format allows the teacher to see that all the students arrive at the same conclusion together. This may be useful when you are introducing a specific concept and want all students to come away with the same information. Activities are usually very structured and, except for any extension questions that may come about, are very straightforward and limit creativity. Teacher-initiated inquiries are good instructional strategies for getting students to consider ways to plan and solve questions. Student-initiated inquiries take an extended amount of time. Often, the teacher may not know where the students' questions will take them. These inquiries, however, provide a means for students to empower themselves by directing the course of their own work.

A summary of each stage is listed in Figure 5.6.

MODIFYING AN ACTIVITY INTO AN INQUIRY INVESTIGATION

Many teachers prefer doing prescribed activities with their students. They are often more comfortable with this type of lesson because it is the way they were taught, or they may want all their students to have the same laboratory experience under the same conditions. Many science teachers are comfortable with doing prescribed activities, or cookbook labs, because they can anticipate the outcome of the experiment or the lab is correlated to a particular concept in the science curriculum. Teachers are often heard saying "I like that particular activity, I've been doing it for years" or "I do it because it's in the textbook."

Changing a traditional textbook activity into an inquiry-based investigation can be relatively easy. It does not mean you have to give up your favorite science activities. Shiland (1999) suggests that meaningful learning does not occur when students are merely following the procedures identified in a prescribed activity. When you realize that cookbook labs and prescribed activities do not meet the instructional goals you have set for your students or that you are ready to adapt some of your (or your textbook's) existing activities, consider modifying your activities in the following ways:

1. *Add an Inquiry Investigation (or Question) to the End of the Activity.* When you add extension and inquiry investigations after the activity, you use the activity as a springboard to inquiry. Encourage students to raise "What if" and "I wonder" questions to take the activity further, or prepare questions as prompts to start students thinking about ways to apply the activity in other investigations.

In the momentum example, the following extension questions could be asked after the initial activity and lead students into more inquiry-based learning:

How does the size of the marble (mass) affect the distance the marble will travel? (Compare a small marble with a large marble or a 1-inch marble with a 1-inch steel ball.)

How does the surface (friction) affect the distance the marble will travel? (Compare it with rolling a marble along a tabletop to a flat rug.)

How could you design a device to enable physically challenged people to go bowling?

How does the length of the ruler affect the distance the marble will travel? (Compare 12-inch, 18-inch, and 24-inch rulers. Will a 24-inch ruler cause the marble to travel twice as far as a 12-inch ruler?)

2. *Look at the Results Section.* If the textbook or activity provides a predetermined data table or graph, remove it. Let the students determine how they will collect and organize the data. Students will have to construct meaning for the data to organize and record them into a table. If they cannot formulate a data table, you can probably conclude that they do not understand the significance and correlation of the data to the activity or they have not mastered strategies for organizing data.

In the momentum example, the data table was provided. What would your students do if the table was not provided and they had to construct their own way to organize the data? Would they be able to do it? Colburn (1996) suggests that many students will be confused at first. Others may record more data than necessary. Others may record data as expected and design a table similar to the one in the original activity.

3. *Look at the Procedure Section.* If the textbook or activity provides a step-by-step list of procedures, remove it. Let the students brainstorm about designing an experiment or

Figure 5.6. Invitation to Inquiry Grid Summary

	Demonstration	*Activity*	*Teacher-Initiated inquiry*	*Student-Initiated Inquiry*
Posing the Question	Teacher	Teacher	Teacher	Student
Planning the Procedure	Teacher	Teacher	Student	Student
Formulating the Results	Teacher	Student	Student	Student

	Demonstration	*Activity*	*Teacher-Initiated Inquiry*	*Student-Initiated Inquiry*
Starter Question	Predetermined	Predetermined	Posed by teacher	Generated by student
Plan or Procedure	Predetermined	Predetermined	Designed by student	Designed by student
Outcome	Predetermined	Expected	Guided towards a concept	Open-ended
Time	5-30 min.	30-60 min.	45-60+ min.	60-120+ min.
Role of Teacher	Active	Provides direction	Guide/facilitator	Facilitator
Role of Student	Observer	Follows direction	Problem solver	Investigator
Materials	Provided	Provided	Suggested	Suggested
Content	Focused	Focused	Needs some focusing	Requires focusing

investigation to answer the original question, prediction, or hypothesis. This makes the activity more like a teacher-initiated inquiry. You can also print the individual steps to the procedure on single strips of paper and give them to students. The students would have to read the steps and sequence them into a logical order.

In the momentum example, a step-by-step procedure was provided for the student to follow. By eliminating this section, students could design their own ways to test the prediction or hypothesis. Encourage students to work in groups and generate possible plans. Have the group choose one (or several) set(s) of procedures to test. After designing the procedure, the students must decide how they will collect and record their data by designing a data table.

4. *Look at the Question Section.* If the textbook or activity provides a starter question to answer, as they usually do, remove it. Start by demonstrating a discrepant event to

observe. Encourage the students to think of questions to investigate. Provide prompts and explorations to engage students in the original question of the activity. By encouraging students to come up with the question or problem, the investigation becomes more personal and meaningful to them. This makes the activity more like a student-initiated inquiry.

In the momentum example, a starter question was provided for the students to test. Consider eliminating the starter question and beginning the lesson with a demonstration or a discrepant event for students to observe. Following the demonstration, students should be provided time to develop "What if" and "I wonder" questions to investigate. The teacher can also provide prompts to guide students in choosing the question from the original activity. The teacher may choose to have students investigate one or several questions together. After the questions are decided, students can determine a set of procedures, a materials list, and a way to collect and record data.

PLANNING FOR INQUIRY

During this chapter, we have looked at ways to categorize science experiences, from demonstrations to student-initiated inquiries. As the teacher designs his or her yearlong plans, the "Invitation to Inquiry Grid" can serve as a way to move students toward more self-directed experiences. If the goal of your science program is to provide students with opportunities to engage in inquiry, planning a gradual shift from left to right in the grid will become a means of ensuring that your students develop investigation skills throughout the school year.

6

Why the Scientific Method Is Important

Chapter 1 offered several myths about inquiry. One of them stated that when students use the scientific method or do problem-solving activities they are doing inquiry. Although the scientific method, problem solving, and inquiry are closely related, some would propose that the three are not exactly the same. This chapter shows the subtle differences and similarities among them.

THE SCIENTIFIC METHOD

As a society, we place great confidence in a product that has been *scientifically tested.* The phrase *clinically proven* provides the consumer with confidence that a product has undergone rigorous testing conditions and is approved by a renowned scientific testing company. We assume that these testing conditions follow the scientific method.

The scientific method is a commonly accepted set of sequential steps or procedures that begin with the identification of a problem or question. The problem is stated as a *testable prediction,* and there is an identified gap between the information that exists and the question being posed.

The hypothesis, or *educated guess,*is based on some prior notion of the outcome of the problem (Macrina, 1995). The hypothesis undergoes rigorous testing through data collection and careful observation to determine the merit of the prediction. Carefully controlling which variable determines the outcome of the experiment, scientists use this time-honored tradition to guide their experiments and discoveries.

Real scientific research seldom follows these prescribed steps as closely as we would like to think. Often, scientific investigations, influenced by human events and endeavors, proceed with so many twists and turns that researchers may find it difficult to follow a single approach. In *The Double Helix: A Personal Account of the Discovery of the Structure of DNA,* Watson (1968) describes how science seldom proceeds in the straightforward and logical manner we might expect. Although scientists and science students still follow a sequential set of steps or procedures in using the scientific method, these steps are not used to provide a rigid structure for the process. Rather, they guide students to think logically, explore all possibilities when studying given phenomena, and add creditability, reliability, and validity to the results and conclusions.

The steps of the scientific method generally include the following:

1. Stating the question or problem to be solved
2. Identifying all possible variables within the problem
3. Constructing a hypothesis
4. Identifying the manipulated variables, the responding variables, and the controlled variables
5. Designing the procedures for the experiment or investigation
6. Determining what supplies, materials, and equipment are necessary to perform the investigation
7. Carrying out the investigation
8. Acquiring data
9. Organizing data on a chart and/or constructing a graph
10. Describing the relationship between the variables
11. Drawing conclusions to determine the validity of the hypothesis
12. Analyzing the results
13. Communicating the results to others

When stating the problem to be solved, begin by asking yourself "What is the question you want to investigate?" State the problem as a "What if" or "I wonder" question. Some explorations might begin with "What," "How," "Which," or "Will." Going back to the marble activity in Chapter 5, the student wanted to explore the relationship between the height of one end of an inclined plane (a grooved 12-inch ruler) and the distance a marble will travel when allowed to roll down it. In this investigation, the question could have been stated as "How does the height of an inclined plane affect the distance a marble will travel?"

To identify all possible variables in the question, the student brainstorms different factors that could affect the outcome of the experiment. He or she makes a list of these factors and later uses the list to control all factors except one, the *manipulated variable.* In the marble activity, these factors included the size of the marble, the length of the ruler, the height of the ruler, the surface the ball rolled on, the height (or position) of the marble when placed in the groove of the ruler, how the marble was released, and the density of the marble. Can you think of other factors that would affect the outcome of the experiment?

In constructing a hypothesis, the student makes a statement or prediction as to what he or she thinks the outcome of the experiment will be. In the marble activity, the hypothesis could have been "As the height of the inclined plane increases, the distance the marble travels will increase."

When identifying the variables of the experiment, the factor or variable that is deliberately changed in the situation is the manipulated variable. The variable that will change as a result of the manipulated variable is called the *responding variable.* In the marble activity, the student deliberately changed the height of the inclined plane. This was the manipulated variable. The distance the marble rolled on the surface, which was measured to determine the result of changing the height of the ruler, was the responding variable. This way, only one variable, the manipulated variable (the height of the ruler), affected the distance the marble rolled. In the experiment, the student used the same size of marble during all the trials, rolled the marble on the same surface throughout the experiment, and placed the marble in the same spot on the groove for each trial of the experiment.

When we allow more than one variable to affect the responding variable or the outcome of the investigation, we don't have a fair experiment. Imagine our marble results if a student had given the marble a little push in some trials but not in others. Pushing the marble during some trials would affect how far the marble rolled as well as the results of the experiment. It would not be a fair experiment.

Designing the procedures for experiments is often difficult for some students. It may be helpful for a student to first brainstorm the design of the experiment and then draw a picture as to what the setup will look like. The drawing can be used to identify and sequence the steps of the procedure. After the student designs the plan, the teacher should review the plan to see if it contains any flaws. In some cases, the teacher, knowing the plan is flawed and will not work as planned, might want the student to do the experiment anyway. There may be some benefit in the student doing the procedures as planned and later, having to determine that the experiment needs a new or revised procedure. In other cases, the teacher can provide hints or prompts to the student to revise the procedure without directly stating what needs to be changed. Too often, young people think of science and the scientific method as the way to search for the "right answer." We need to assure them that making mistakes and learning from them is all part of the learning process in science (Sprung, Froschl, & Campbell, 1987).

While designing the procedure, the student should determine what supplies, materials, and equipment are necessary to carry out the investigation. The student can go back to the drawing and identify what is needed for the experiment. In the marble activity, the materials list was provided to the student.

Students must also consider how to acquire and organize data. If a data table is not provided in the activity, it should be done as part of planning the procedure. After the data are collected, the student can produce a visual representation of the data by graphing the results. Graphs are an excellent means of studying patterns and relationships between the variables, reinforcing math skills, and providing evidence of student work that can be posted in the classroom.

When asked to describe the relationship between the manipulated and the responding variables, students often have difficulty drawing reasonable conclusions. One reason may be that teachers sometimes fail to emphasize this step in the data analysis. Before students can analyze their results, they must first see a relationship between the two variables. As the manipulated variable increases, what happens to the responding variable? Does the graph form a straight line? A curved line? In the marble activity, the student would have first looked at the data table and compared the two columns representing the variables. As the height of the ruler increased, what happened to the distance the marble rolled? Only by describing the relationship between variables can students draw accurate conclusions from their data and analyze their results. This is a skill that can be practiced by showing students various data tables and graphs and asking them to describe the relationship between the two variables.

After the results are analyzed, the student uses the data to determine the validity of the hypothesis. Do the data support or refute the hypothesis? Is the hypothesis accurate? If not, how should the hypothesis be restated, and what new experiments should occur?

The final step of the scientific method lies in communicating the results. This may be done in different ways. The results can be written up as a laboratory report identifying each step of the experiment, or the student could do an oral presentation in front of the class to share his or her findings. When students have been working in groups, the teacher may want to hold a *convention* in which each group presents its findings and makes a trifold poster board of its results. The convention can be videotaped and shared with parents during an open house or other school event.

The communication phase of the scientific method allows the teacher and the students to reflect on the procedure followed, share their conclusions, and make recommendations if the experiment is to be repeated. By critiquing and communicating the procedure, students can assess how well they or their group functioned and evaluate the quantity and quality of their learning. During the communication phase, students who worked together in groups can process each group member's contribution to help maintain a collaborative atmosphere and effective working relationships (Johnson, Johnson, & Holubec, 1984). By providing closure to the investigation, the teacher and students celebrate the learning process and are rewarded for a job well done. It also provides a time to record other "What if" questions that arose during the investigation and will lead to new inquiries.

"EXPLORING MOMENTUM WITH RAMPS AND BALLS"

For children in Grades 1 through 3, the scientific method can be reduced to a few simple steps. By taking the same momentum example, we can see how the scientific method can be applied with younger children. Once a question or problem is posed, the children are involved in four basic steps: (a) predicting (or guessing) the outcome, (b) conducting and observing the experiment, (c) documenting the results, and (d) discussing the outcome (Sprung et al., 1987).

The following inquiry investigation has been adapted from *What Will Happen If . . . . Young Children and the Scientific Method* (Sprung et al., 1987). Preinvestigation activities for "Exploring Momentum With Ramps and Balls" may include having the teacher set a purpose by gathering the children during *circle time* to explain that they will become scientists and participate in a scientific experiment. Children should be told that they will be predicting (or guessing) the outcome, conducting and observing the experiment, and documenting and discussing their results. Other preinvestigation preparations may include having the teacher ask the children what they know about ramps and rolling balls, which could help to assess their preconceptions and possible misconceptions about momentum. Their comments and questions can be written on a chalkboard, poster, or easel paper. Some class time may also be spent by setting expectations for individual behavior and group participation. The children's comments on ramps and rolling balls can lead the teacher to pose the question, "How will the height of the ramp affect the distance a ball will roll?"

Predicting an Outcome

Let's return to the children's predictions for the experiment. They can be written as simple statements, such as "The higher the ramp, the farther the ball will roll." For younger children, the teacher can write one prediction for the entire class. Older children or more experienced classes can have each group make its own prediction. In either case, the teacher should spend some time reviewing the prediction(s) to ensure that all children understand the purpose of the task. Often, having a student repeat the prediction or reword it for another student can provide the teacher with enough feedback to assess whether they actually understand the prediction to be tested.

Conducting and Observing the Experiment

During the first half of this step, the teacher should decide whether to have the entire class brainstorm about setting up the experiment or to have each group come up with its own procedures. Younger students may or may not have enough experience testing their scientific ideas to independently suggest their own procedures. The teacher's interaction with the class and the children's prior experience should determine which path the teacher follows.

First, the teacher will instruct the groups to place a strip of masking tape across the floor. This will mark the location and position for the bottom of the ramps and ensure that all the balls start rolling on the floor from the same place.

Given two 2-inch by 4-inch boards (each 3 feet long) and six smaller 2-inch by 4-inch blocks (about 6 inches long), one group will build a ramp using the two long boards propped up at one end by one smaller block. The bottom of the ramp should line up with the strip of masking tape. The two long boards should be separated by a gap to form a groove for the ball to roll down. Students can use the width of the smaller block to measure the gap between the two long boards. A second group will build a similar ramp using two blocks to prop up the boards, and a third group will use three blocks (see Figure 6.1).

Through class discussion, the teacher should point out that all ramps must be built and lined up the same way to make this a fair experiment. The teacher may explain how variations in building the ramps could alter the results.

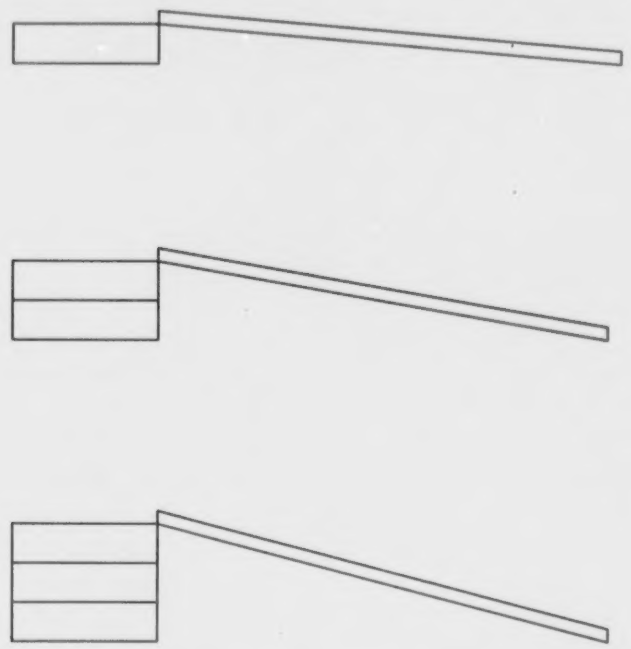
After the ramps are built, the teacher should state the original question, "How will the height of the ramps affect the distance the ball will roll?" Students should understand the connection between the question to be studied, the materials, and the setup procedure being used. At this time, the teacher should have students pose their predictions and understand the correlation between the prediction made and the setup procedure. Students can then brainstorm about how they will measure the distance the ball rolls. The teacher may want to suggest that the children use small pieces of tape or adhesive dots to mark the spots where the balls stop rolling.

When the predictions are made, the teacher should hand each group a tennis ball to roll down the ramp. The teacher may point out the need to release the ball without pushing it down the ramp. Depending on the level of the class, students may want to devise a way to release the ball the same way in all cases. Some students may discover that using a stick to act as a "gate" to release the ball down the ramp is a good way to start the ball rolling.

Documenting the Results

Children may discover that they need to repeat the procedure several times. I have not yet seen a class of young scientists that were content to let the ball roll down the ramp just once! They can use the tape or dots to mark the locations of the furthest distance the ball traveled, or some classes may want to use measuring sticks. Each group can now write its results on the poster or easel paper.

Figure 6.1. Three Ramps



Discussing the Results

When the procedure is completed, ask the class what they observed and learned. Several questions can guide their thinking:

Which ramp made the ball roll the shortest distance?
Which ramp made the ball roll the farthest distance?
Did the ball roll as far as you predicted?
How accurate were your predictions?
Were some predictions more accurate than others?
How can we show our results on a chart or graph?

At this point, the students should come to the understanding that the ramp with three blocks caused the ball to roll farther than the ramp with one or two blocks. Having individual members of the class summarize the investigation will help the teacher assess the students' understanding of ramps and rolling balls. By providing a discussion and summary of the experiment, students can now pose any additional and related questions they have.

More "What Will Happen If . . ." Questions

The value of any good investigation lies in its ability to generate more questions in children's minds. The ramp and rolling ball investigation will surely invite other questions for students to investigate:

What will happen if we use four blocks? Five blocks?
What will happen if we place the ball on a ramp without blocks?
What will happen if we use a basketball instead of a tennis ball?
What will happen if we use a bowling ball?
What will happen if we roll the ball on different surfaces?

The description of the ramp and ball activity is one of several ways to investigate momentum with young children. Depending on the size and makeup of the class, the teacher may choose to demonstrate a ramp with one ball and pose questions such as "What would happen if we added one more block to the ramp?", "What would happen if we increased the height of the ramp?", and "How does the height of the ramp affect how far a ball will roll?" Any of these questions would provide a sufficient invitation to inquiry following the single-block demonstration. In this situation, the teacher uses a demonstration to introduce a teacher-initiated inquiry.

In the ramp activity, the class was divided into groups, with each group testing momentum for a different height of the ramp. Depending on the number of ramps, blocks, and balls available, an alternative strategy would be to have each group complete the procedures for one, two, and three blocks. This alternative maximizes the involvement of the groups. Another alternative could have the teacher demonstrating the ramp with one ball and calling on individuals or small groups to test the different number of blocks, one at a time, in front of the entire class.

A WORD OF CAUTION

As stated in *National Science Education Standards* (*NSES*) (NRC, 1996), doing inquiry does not mean following the sequential steps of the scientific method. The scientific method has its distinct purpose in the scientific community. Understanding the number of great discoveries and inventions in our world that have come about because of, or in some cases in spite of, the scientific method renews our faith in its ability to guide the process of inquiring. To do inquiry well, however, teachers and students must use the logic of the scientific method rather than seeing it as a structured set of steps to follow. Only then can we appreciate what the scientific method provides us: a general guideline for investigating questions and solving problems.

SCIENTIFIC PROBLEM SOLVING

Albert Einstein is quoted as saying "The formulation of a problem is often more essential than its solution." Problem solving, like inquiry, is often thought of as a way of thinking and processing information that enables students to construct understanding through personally meaningful experiences as they become competent decision makers. Hunkins (1995) describes problem solving as an "heuristic organizer that allows us to contemplate ways in which we can and perhaps should organize and reorganize knowledge to solve a perceived difficulty" (p. 11).

In a problem-solving situation, one often uses one's abilities to analyze a situation and design a way to solve the problem. Problem solving is found in all subjects and disciplines.

In this chapter, the way we describe and detail scientific problem solving is different from the way we would describe mathematical problem solving. Problem solving in the scientific sense is a systematic and orderly way to explore new situations and generate solutions to real problems and discrepancies that face us. Gagne (1970) suggests that problem solving can be viewed as a process through which the learner discovers a combination of previously learned rules that can be applied to achieve a solution for a novel situation. Hester (1994) describes problem solving as an activity that engages and stimulates the learner in the movement toward problem and/or conflict resolution. Hester also makes a primarily developmental differentiation between inquiry and problem solving. He believes that

> although inquiry processes resemble problem solving and include many of the same procedures as early reasoning, there is a fundamental difference—problem solving and formal reasoning require the ability to reason abstractly . . . and make logical deductions. On the other hand, inquiry is tied to concrete thinking, factual information and the use of sensory (discovery) learning. Inquiry is less formal, less structured, and partakes of hands-on learning in which fully developed scientific reasoning is not required. (p. 22)

Although inquiry and problem solving are closely related, in problem-solving situations the problem is often provided by the teacher and the students use scientific reasoning skills to develop a solution to solve the problem. Referring back to the inquiry grid, we can see that problem solving is similar to teacher-initiated inquiry. The central emphasis is on designing an outcome or product.

As an example, one problem-solving activity may involve students designing and building a container to keep an ice cube from melting over a period of 24 hours. The teacher may place limitations on the task as to the size or weight of the container. The students would decide the shape and the materials used in making up the container. To solve the problem posed to the students, they will need to (a) design a container by brainstorming and generating possible solutions, (b) research the advantages and disadvantages of each design, (c) make models and illustrations of their designs, (d) choose which design to make, (e) test the design to solve the problem, and (f) communicate their results.

Before testing the designs, the class would also need to discuss and determine a way to measure the rate of melting after the period of time. Two possibilities are to weigh the mass of the ice cube or measure the amount of melted water after 24 hours.

SCIENTIFIC PROBLEM SOLVING VERSUS INQUIRY

In problem-solving situations, students are faced with a dilemma and are asked to devise a solution to the problem. Generally, problem-solving activities start with a problem and end with a product that bridges the gap between a present condition and a desired condition. Examples of problem-solving experiences include

- Designing and making a container that will keep an ice cube from melting
- Designing and making a container that will keep a liquid hot as long as possible
- Designing a filtration system using cotton, gravel, sand, and charcoal to purify dirty water

- Designing and making a wallet for a visually impaired person
- Designing and making a bridge that will support the most weight possible

Inquiry, on the other hand, involves students in observing and exploring a particular phenomenon to raise worthy questions of interest. In inquiry situations, the process of seeking answers to questions usually results in expanding students' understanding of a concept. For example, while exploring and observing the rate at which a small marble falls within a cylinder of a thick liquid, such as corn syrup, students will raise additional questions, such as

How does the size of the marble affect the rate at which it falls?
What would happen if I dropped a marble in different liquids?
Does soap detergent or different grades of motor oil affect the rate of fall?
Does adding water to the corn syrup affect the rate of fall?

A MODEL FOR SCIENTIFIC PROBLEM SOLVING

Although various models of scientific problem solving are available, they generally include the following components:

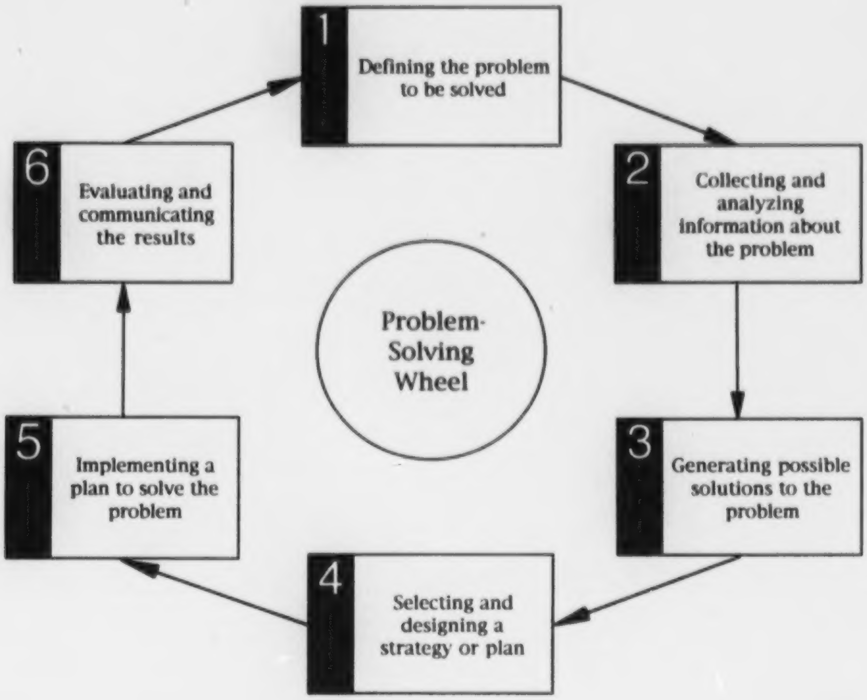
1. Recognizing that a problem exists and defining the problem to be solved
2. Collecting and analyzing information about the problem
3. Generating possible solutions to the problem
4. Selecting and designing a strategy or plan
5. Implementing a plan
6. Evaluating and communicating the results

Often, the components of the problem-solving process are illustrated as a wheel or cycle rather than the linear progression of steps typical of the scientific method. This implies that problem solving is a systematic, cyclical process in which investigators sometimes return to steps and various stages of the cycle. A typical problem-solving wheel is shown is Figure 6.2.

As a middle school or high school level example, consider the following problem-solving task: As a laboratory technician, you are presented with the problem of determining the relative amounts of two compounds in a mixture. You have been given a 10-gram sample of a mixture of sugar and sand. Your task is to design a procedure for determining the percentage of the mass of sugar and the percentage of the mass of sand in the total mass of the sample. Once you have planned your procedure, follow it carefully and report your findings.

In Step 1 of the wheel, the student recognizes that a problem exists and defines the central problem to be studied. According to Hester (1994), recognizing that a problem exists is usually the first step in critical thinking. This is usually accomplished by identifying a discrepancy or uncertainty with the given phenomenon. The problem to be investigated should be written as a statement so that all members of the group have a common understanding of the problem. The problem should ideally be something meaningful to the students and worth their time to solve. Often, in defining the problem, students consider the

Figure 6.2. The Problem-Solving Wheel


1
Defining the problem to be solved
2
Collecting and analyzing information about the problem
3
Generating possible solutions to the problem
4
Selecting and designing a strategy or plan
5
Implementing a plan to solve the problem
6
Evaluating and communicating the results
Problem-Solving Wheel

dilemma between the *present state* versus the *desired state*. This places the problem in concrete and understandable terms.

In Step 2, the student uses critical thinking and research skills to collect relevant information about the problem. Each uses resources to analyze the stated problem and raise possible solutions. In the sugar and sand problem, a student may rely on his or her prior knowledge about solubility, mass evaporation, and filtration to solve the problem.

In Step 3, the student brainstorms possible solutions to the problem and weighs the value of each solution. In this step, each student in the group communicates his or her ideas and thoughts on the problem. Here, the student is encouraged to "think outside the box" and generate various possible solutions to the problem. Two- and three-dimensional models can also be designed to illustrate plausible solutions.

In Step 4, the student selects the best solution from those generated in Step 3 and plans a procedure to solve the problem. The procedure should be logical and sequential. A list of supplies, equipment, and resources needed to solve the problem are usually identified in this step. In the sugar and sand task, students may choose to use a triple-beam balance, filter paper, a funnel, beakers, a heating source, an evaporating dish, a ring stand, and stirring rods. In some situations, students may also identify measures to evaluate the success and effectiveness of their solution.

In Step 5, the student implements the plan and procedures written in Step 4 to solve the problem and collects information from the procedures. In some cases, the data collected may be organized on a graph or table.

Finally, in Step 6, the student reviews the data collected and evaluates the solution to the problem. The results are usually communicated in a written report or orally to the whole class. In some cases, the data may support the solution to problem. In other cases, new solutions must be generated, sending the group back to Step 2.

WHY WE DO SCIENTIFIC PROBLEM-SOLVING ACTIVITIES

Engaging students in problem-solving situations in science opens the door for opportunities to integrate higher-order thinking skills across the curriculum. During Steps 1 through 3 of the problem-solving process, students are usually involved in sharing their commonly held theories, comparing and contrasting their ideas and understandings, justifying their positions and theories, analyzing relevant information, choosing avenues of action, and explaining and evaluating alternative solutions. During Steps 4 and 5, students put their collective reasoning skills into action by implementing a possible solution to the problem. Often, prototype designs of actual models are constructed to test possible solutions. In the final step, students evaluate their observations, analyze the success of the solution posed, and communicate their results to others.

Watts (1991) identifies eight reasons to provide students with problem-solving experience:

1. Problem solving enables youngsters to assume ownership of a task.
2. Problem solving encourages decision-making and social skills.
3. Problem solving is a form of both active learning and discovery learning.
4. Problem solving is a vehicle for teaching many scientific skills and for reaching the content aspects of science.
5. Problem solving allows for cross-curricular and interdisciplinary activities.
6. Problem solving provides relevance and real-life contexts.
7. Problem solving is among the highest and most complex forms of human activity.
8. Problem solving enhances communication.

Problem solving encourages positive scientific attitudes by promoting curiosity, cooperation among group members, confidence, responsibility, discourse, active participation, questioning, decision making, persistence, self-reliance, independence, and an atmosphere of excitement in the classroom.

7

What Is the Learning Cycle?

I can still remember my high school chemistry teacher. He lectured from Monday through Thursday on some abstract chemical concept and then on Friday gave the class a lab that seemed to prove that what he said on Monday was correct! As I sat in class during those long lectures, the words seldom made much sense to me. My teacher's lessons always started with chemistry vocabulary terms and information that seemed to take up most of the 45-minute periods. For many of us in the class, the lessons did not make any sense until we were able to actually experience the concept by doing the laboratory work. For me, Friday was always the "now I get it" day.

I also remember my eighth-grade life science teacher. She taught in just the opposite way. She would start with a hands-on experience and later make sense of the experience by providing the background information on what we just did. She did not seem to be driven by lecturing; rather, she was more concerned about how to engage students and have them actually *do* science.

In her unit on photosynthesis, the teacher would get us thinking about the leaf as the manufacturing site. She did this by having us to think about what would happen to the leaf of a bean plant if it were covered with some material. Some students chose to cover one or both sides of the leaf with Vaseline, peanut butter, or even nail polish. Others chose to cover the leaf with aluminum foil, wax paper, or clear transparent wrap. These investigations provided an opportunity for us to observe changes in the leaf. Following the plant investigations, the teacher introduced the process of photosynthesis and had us think about how our findings in the initial investigation related to the food-making process. She introduced appropriate concepts about photosynthesis and terms such as *stomata, chloroplast, chlorophyll, veins,* and so on. She also helped us apply and extend our learning to new situations by discussing how pollution from cars affected the growing rates of plants.

In this chapter, we see how the Learning Cycle complements a constructivist view of learning and how this approach can be used to structure inquiry-based lessons in science. By understanding Piaget's stages of cognitive development, in which children progress from concrete to formal operations, we realize that it is important to introduce a concept by providing a concrete, motivational experience before introducing new information.

WHAT IS THE LEARNING CYCLE?

The Learning Cycle is one of the most familiar and effective models for science instruction. It was originally proposed in the early 1960s by Atkin and Karplus (1962). The model was later used as the instructional basis for the Science Curriculum Improvement Study (SCIS) program, by Karplus and Thier (1967). It was further documented by Lawson, Abraham, and Renner (1989), Barman and Kotar (1989), Beisenherz and Dantonio (1996), Marek and Cavallo (1997), Bybee (1997), Abraham (1997), and Colburn and Clough (1997).

According to Beisenherz and Dantonio (1996), the Learning Cycle

> enables students themselves to construct discrete science concepts. It includes an Exploration Phase, in which students are exposed to hands-on activities; an Introduction Phase, in which a concept is formally introduced; and an Application Phase, in which the concept is reinforced and expanded through additional experiences. All phases of the Learning Cycle use teacher questions to guide the learning experience. (p. vii)

Initially, the Learning Cycle was proposed as a 3-phase model (Exploration, Concept Development, and Application). In another model, however, Martin, Sexton, and Gerlovich (1999) suggest *4 Es* (Exploration, Explanation, Expansion, and Evaluation). With the recent emphasis on constructivism and assessing prior knowledge, the Engagement phase has been added (see Figure 7.1), making the Learning Cycle a *5-E* model:

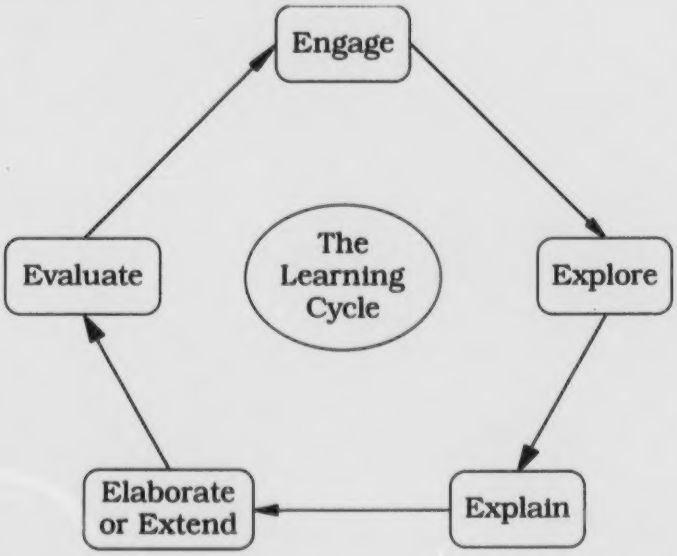
- Engagement
- Exploration
- Explanation
- Elaboration or Extension
- Evaluation

We will see that when teachers plan lessons and units around the 5 stages of the Learning Cycle, students move from concrete experiences, to the development of understanding, to the application of principles.

During the Engagement phase, the teacher sets the stage for learning. This is accomplished by stating the purpose of the lesson. Often, the teacher introduces the topic of the lesson and states the expectations for learning by explaining what the students should know and be able to do by the end of the lesson or unit. The Engagement phase is also a means of getting the students' attention and focus. By using attention-grabbing demonstrations and discrepant events (Liem, 1987), the teacher creates ways to *hook* the students into learning. Discrepant events generate interest and curiosity, which sets the stage for inquiring about a particular phenomenon. Discrepant events serve to create cognitive dissonance, or in Piaget's words, disequilibrium, because the observation of such events does not readily assimilate into the students' presently held understanding. Because the observations made from discrepant events run counterintuitive to the students' prior experience, they quickly activate students' questions.

From a constructivist perspective, the Engagement phase also provides an opportunity for the teacher to activate learning, assess prior knowledge, and have students share

Figure 7.1. The Learning Cycle



their prior experiences about the topic. During the Engagement stage, the teacher can note possible naive conceptions or misconceptions stated by the students. These misconceptions can be addressed while the students have an opportunity to work through the Exploration and Explanation stages and afterward. It should be noted that it is nearly impossible for any teacher to ascertain all misconceptions held by all students. However, the Learning Cycle—specifically the Engagement stage—does provide the teacher with a means of assessing students' current beliefs and understandings.

The Exploration stage is an excellent time to engage students in inquiry. During this stage, students raise questions, develop hypotheses to test, and work without direct instruction from the teacher. They go about collecting evidence and data, recording and organizing information, sharing observations, and working in cooperative groups. The Exploration stage enables students to build on a common experience as they go about their investigation. This common experience is essential because students will enter the classroom with different levels of experience and knowledge about the topic being studied. The Exploration stage enables all students to experience hands-on learning and helps "level the playing field" within a culturally diverse classroom. The Exploration stage also provides opportunities for students with diverse experiences to share their different understandings and broaden the perspective of the entire class.

During the Exploration stage, the teacher may choose to assign roles to the individual students working in a group or let students choose the role according to their strengths or interests. Students may assume the recorder, materials collector, reader, or group manager role.

Following the exploration, the teacher should (a) have the students remove the equipment and supplies from their desks and (b) use their acquired data to begin a period of reflection in which they discuss what was discovered and learned from the exploration.

During the teacher-directed Explanation stage, the teacher facilitates data- and evidence-processing techniques for the individual groups or entire class (depending on the nature of the investigation) from the information collected during the exploration. The information is discussed, and the teacher often explains the scientific concepts associated with the exploration by providing a common language for the class to use. This common (or scientific) language helps students articulate their thinking and describe their investigations and experiences in scientific terms. The teacher can continue to introduce details, vocabulary terms, and definitions to the lesson as students assimilate their understanding with the scientific explanation. This can be accomplished by using direct instruction or lecturing, audiovisual resources, on-line sources, and computer software programs. Here, the teacher uses the students' prior experience to explain the concepts and attempts to address misconceptions uncovered during the Engagement or Exploration stages.

The Explanation stage is sometimes called the *concept development* stage because evidence and newly developed concepts are assimilated into the cognitive structure of the student. During the Explanation stage, students may work to (a) assimilate or accommodate new information as they make sense of their understanding and (b) construct new meaning from their experience.

During the Elaboration or Extension stage, the teacher helps reinforce the concept by extending and applying the evidence to new and real-world situations outside the classroom. This stage also facilitates the construction of valid generalizations by the students, who may also modify their presently held understandings of the phenomena being studied.

During the Evaluation stage, the teacher brings closure to the lesson or unit by (a) helping students summarize the relationship between the variables studied in the lesson and (b) posing higher-order questions that help them make judgments, analyses, and evaluations about their work. Connections among the concepts just studied can be illustrated by using a concept map. Here, the teacher can compare the prior knowledge identified during the Engagement stage with the newly formed understanding gained from the lesson.

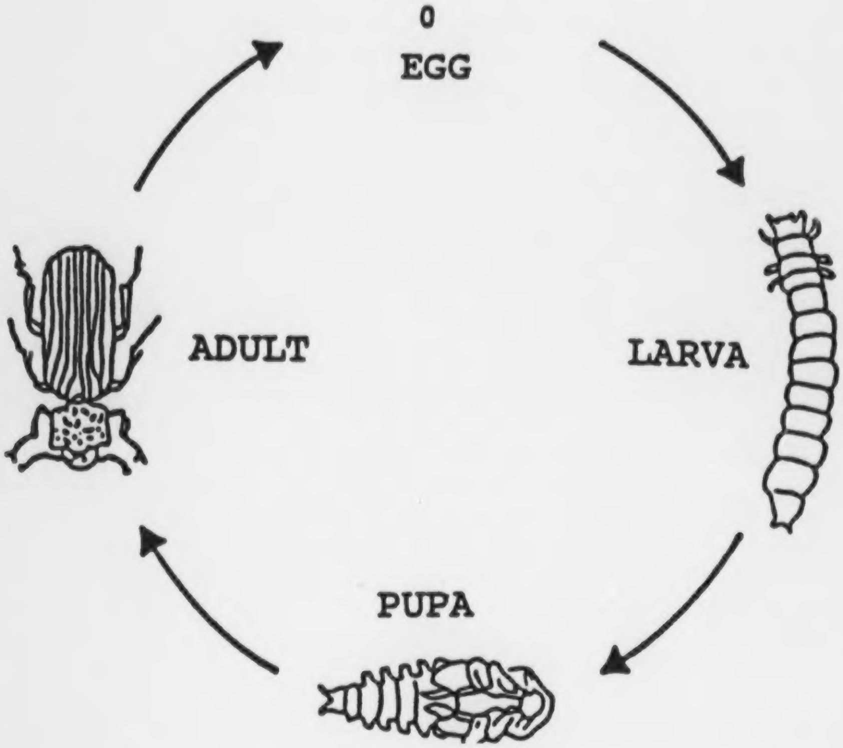
In the area of assessment, the teacher will provide a means for students to assess their learning and make connections—from prior understanding to new situations that encourage the application of concepts and problem-solving skills. Assessment strategies may include monitoring charts or checklists, portfolios, rubrics, and student self-evaluations.

"MEALWORMS TO GO": A STUDENT-INITIATED INQUIRY

Studying mealworms is an excellent way to introduce students to a life science unit on invertebrates, insects, life cycles, metamorphosis, and the needs of living things. "Mealworms to Go" involves students in learning about an invertebrate animal through inquiry and questioning. This 2-week unit follows the 5-E Learning Cycle format and is appropriate for Grades 4 through 8.

Prior to the start of the unit, the teacher should obtain a source for mealworms. Mealworms are readily available from pet stores and are quite inexpensive. The teacher should also contact another teacher, preferably at the same grade level, within the state so that both classes are completing the unit simultaneously. This will allow both classes to share (possibly by electronic mail) what they are learning about mealworms and also to exchange their mealworm packages to compare packing designs and the number of live mealworms reaching their destinations.

Figure 7.2. Life Cycle of a Mealworm



The Engagement Stage

To start the unit, the teacher may assess prior knowledge by showing students several mealworms and asking them what they already know about these little creatures. Some students may have little or no experience with mealworms, but others may tell you that they have studied mealworms in other science classes or have used them as bait for fishing or as food for pet turtles. The students could record their responses and experiences in their science journals and then pair and share that information with a partner. The teacher should solicit responses from the students to allow them to communicate their prior experiences (and misconceptions). The teacher can write their comments on a blackboard or overhead by making a concept map or list of "What we know about mealworms." The teacher should also be aware that many students may think that mealworms are worms. The mealworm is actually the larval stage of the beetle, *Tenebrio molitor* (see Figure 7.2). It may be best to wait until the end of the Explanation phase, when students have had an opportunity to learn more about mealworms, to change this common misconception.

Before beginning the investigation, students can brainstorm a list of rules called the "Mealworm Bill of Rights."This enables students to create their own rules to follow while they handle the mealworms and identify proper procedures for animal care and responsibility.

The next step in having students become "mealwormologists" is to encourage them to make firsthand observations about the mealworms to find out everything they can about them. During this time, students should use magnifying lenses and measuring rulers to observe and collect information about the mealworms. (Students need to be reminded to wash their hands before and after handing the mealworms to ensure proper safety and sanitary conditions.) Observations about the mealworms' size, color, number of "legs," movements, and so forth will be recorded in their science journals. Students should also be encouraged to use various sources of information both in the library and on the Internet to determine the scientific name of the mealworm and to gather more information about the life cycle of the beetle. The information they collect will help them during the Extension phase when they design their "Mealworms To Go" containers.

As they observe and collect information about the mealworm, students also write questions about mealworms that they want to investigate. Questions may include

What do mealworms prefer to eat?
Where do mealworms live?
Do mealworms prefer to stay in sunny or dark areas?
Do mealworms prefer wet or dry surfaces?
Do mealworms have eyes? How do they know where they are going?
Are mealworms really worms?
Are mealworms related to earthworms?
What materials do mealworms like for bedding?
Do all mealworms have the same number of segments?
Do mealworms prefer hot or cold locations?
How fast does a mealworm travel?
Can mealworms walk up an inclined ramp?
I wonder, can a mealworm go through a maze to find its food?

In the final part of the Engagement, the teacher and students identify and classify the questions into three categories: ones that can be answered by experimenting, ones that need to be revised before being answered by experimenting, and ones that should be answered by library research and other expert sources.

The Exploration Stage

During the Exploration stage, students plan and carry out their investigations. After the questions are clearly stated, the students should plan on the way they expect to go about finding answers to their questions and the materials they will need to complete their investigations. Here, the teacher can provide several prompts and suggestions, and students can begin planning their investigations using an *inquiry data sheet* (see Form 7.1).

The inquiry data sheet can serve as a format for students to write and organize their investigations. Before beginning the actual investigation, students should critique each other's data sheets. Students can help each other determine whether the procedures are clear and understandable.

After the inquiry data sheets are completed and the teacher has approved the procedures, the students are ready to carry out their investigations.

FORM 7.1

MEALWORM INQUIRY PLAN

I wonder (my question is) ______________________________

____

I predict (my hypothesis is) ______________________________

____

The manipulated variable is ______________________________

The responding variable is ______________________________

The controlled variables are ______________________________

The steps I followed (my procedure is)

1. ____
2. ____
3. ____
4. ____
5. ____

The observations I made (my data are) ________________________

____

____

The data are organized on a chart or graph. The patterns or relationships found ____

____

____

The answer to my question (my conclusion is) __________________

____

____

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The Explanation Stage

At the completion of their investigations, students need time to organize their data into charts, tables, or graphs and look for patterns and relationships. During the Explanation stage, students will use this data to communicate to the class what they found out about mealworm behavior during their inquiries. The teacher can organize a "Mealworm Convention," in which student mealwormologists will present their findings during 3-minute presentations. Students may also be required to make and use posters or trifold display boards to summarize their observations and results.

The Elaboration or Extension Stage

The Elaboration or Extension phase for this unit becomes a problem-solving or performance task. Students use the information they gathered during their investigations to design a shipping container that will enable them to send 25 mealworms to another science classroom (the cooperating class) in another school. The container's design should ensure the maximum survival of the mealworms. The success of the container will be measured by determining and comparing the survival rates of the mealworms between the two classrooms.

The Extension stage begins by having the teacher introduce the students to the cooperating class. The classes can share information about their members by providing their names, school demographics, and so on. Sharing photographs and exchanging letters either by postal service or by e-mail are also suggested.

After being presented with the task, the students undertake the design of containers that would be appropriate for shipping mealworms to the cooperating class so that they arrive *still in the larva stage*. Students should be given time to brainstorm some questions about designing an appropriate container. A group of eighth graders, for example, would be likely to pose these kinds of questions:

How will food and water be kept in the container?
How long will it take for the package to arrive at the cooperating school?
Does the United States Post Office have requirements for transporting live animals?
How would the package be constructed differently if the package were sent in December rather than in May?
What will be used to cushion and protect the mealworms?
How many days does it take to complete the beetle's life cycle?
How old do the mealworms have to be so that they arrive in the larva stage?
What criteria will the two classes use to determine whether a mealworm arrives alive or dead?
Should there be size and cost limitations for the containers?

Working in cooperative groups, several prototype containers can be made. A class vote can determine which design will represent the respective schools.

After the containers are completed, each class will simultaneously ship the mealworms to the students in the cooperating school. When the class receiving the mealworm package from the cooperating school arrives, a videotape recording can be made of the opening of the containers. The video can then be sent to the cooperating class to view.

Following the opening of the package, the number of living and dead mealworms should be counted and recorded. The survival rate should be calculated by the previously determined criteria. Groups will then send the videotapes of the container opening and survival rates to the cooperating class. After this has been completed, it's time to move on to the final E: Evaluation.

The Evaluation Stage

Like science instruction, assessment and evaluation measures are changing to assess concepts and understanding, not just facts. With the changing pedagogy in science education, assessment has also moved to emphasizing a combination of hands-on and *minds-on* skills (Hein & Price, 1994). Assessment procedures must align with the new goals and objectives of the national standards to ensure that learning has occurred.

According to *National Science Education Standards* (NRC, 1996),

> Assessment and learning are two sides of the same coin. The methods used to collect educational data should teach what students should learn. And when students engage in an assessment, they learn from it [assessment] is an effective tool for communicating the expectations of the science education system to all concerned with science education. (p. 76)

That is to say, if you provide your students with low-level recall questions, you communicate the idea that memorizing scientific facts is an essential part of learning. If you provide your students with writing and extended-response questions, you are saying that communication, especially in written form, is an important way to demonstrate their understanding of science. By providing students with performance tasks such as "Mealworms to Go," you communicate to students ways "to apply scientific knowledge and reasoning skills to situations similar to those they will encounter in the world outside the classroom, as well as to situations that approximate how scientists do their work" (NRC, 1996, p. 78).

To begin our discussion about the final phase of the Learning Cycle, we first must start by distinguishing between assessment and evaluation. Assessment is the process of gathering information about students—what they know and can do—whereas evaluation refers to the process of interpreting and making judgments about testing and assessment information (Hart, 1994). Start by asking "What are the scientific concepts, skills, and competencies a student should know and be able to demonstrate by the end of this unit?" Many will obviously say that content and basic science knowledge acquisition are most important. And many of us will agree with that. Although expanding one's scientific models and conceptions about mealworm and invertebrate animals is important, some could argue that other scientific, thinking, and social skills are equally important. For that reason, the assessment of an inquiry lesson or unit should model the tenets of inquiry as closely as possible. It would be ineffective to design a unit test for "Mealworms to Go" based on multiple-choice or true-false objective questions that measure knowledge or recall-level understanding. The assessment instrument should reflect the goals and objectives of the teacher's instructional plans and include aspects of collecting data about

1. Scientific knowledge and information (the life cycle of the mealworm)
2. Science process skills (observing, measuring, predicting, formulating a hypothesis, designing a procedure, recording data, etc.)
3. Problem-solving skills (designing solutions or choosing best alternatives)

4. Communication skills (oral presentations and written journal entries)
5. Cooperative learning (group work and responsibility)

To match these goals, the assessment instruments for inquiry instruction usually incorporate several authentic, alternative forms, such as portfolio entries, rubrics, monitoring charts, concept maps, and self-evaluations.

AUTHENTIC ASSESSMENTS

"Not everything that counts can be counted and not everything that can be counted counts." This saying was reportedly posted in the office of Albert Einstein (Herman, Aschbacher, & Winters, 1992) and summarizes the growing importance of alternative and authentic assessments in education.

Authentic assessments are defined as evaluation strategies that are unconventional, student centered, meaningful, interesting, and relevant to the learner. When compared with objective-type questioning techniques, authentic assessment involves active participation and, usually, higher-level thinking skills. Although multiple-choice and true-false items do serve a specific purpose by assessing the knowledge that a student can memorize, authentic assessments paint a more realistic picture of what the student understands and is able to do. Authentic assessment also complements the varying styles of learning that students display and involves them in choosing how they will be evaluated.

The challenge to teachers of inquiry is using assessment procedures that complement what is valued in instruction. When choosing assessments for science, the National Center for Improving Science Education (NCISE; 1992) recommends that inquiry-based teachers consider

1. Assessments that match exemplary science instruction
2. Assessments that include hands-on performances
3. Assessments that probe the depth of the student's understanding
4. Assessments that emphasize the process used to obtain an answer as well as the product or the final answer itself
5. Assessments that include opportunities for self-evaluation
6. Assessments that include performances such as presentations, journals, and displays
7. Assessments that involve group work designed around tasks too complex for students to undertake individually

PORTFOLIOS

A portfolio is a folder or container holding evidence and representative examples of student work, accomplishments, and performances that are collected, reflected on, and saved over an extended period of time. Using portfolios, the work of the student is reviewed against specific criteria to make evaluations and judgments about the student's progress and improvement. Each entry in the portfolio is a selected piece of work that exemplifies significant accomplishments achieved by the student. The entries may be works in progress or finished products. In the "Mealworms to Go" unit, a completed inquiry data sheet could be evidence that students may add to their portfolios to demonstrate their ability to (a) pose a question, (b) plan an investigation, (c) gather data, and (d) draw reasonable conclusions. Other examples of possible portfolio entries are excerpts from science journals, illustrations or artwork for the life cycle, a summary of contributions to the container design task, or a writing assignment that describes what has been learned about mealworms and their life cycles.

By combining portfolios with traditional objective testing, teachers, students, and parents can collaborate to paint a realistic and more complete picture of a child's performance and academic growth over time. When evaluation involves portfolios and performance tasks, students are motivated to demonstrate what they can do in completing complex tasks. The portfolio is now becoming one of many effective tools for assessing inquiry-based learning.

RUBRICS

The word *rubric* comes form the Latin word meaning *red*. The word originally referred to notes and directions written in red (to distinguish them from the rest of the text) in the margins of liturgical books for conducting religious services. Today, teachers and students use rubrics as guidelines for scoring, assessing, and evaluating student work and performance. Rubrics provide assistance in (a) describing the performance of students at various standards or levels of proficiency, (b) scoring and assessing student work without bias and inconsistency, and (c) enabling students to compare and discuss their self-assessment with the teacher's evaluations.

Instructional rubrics usually contain three features:

1. Dimensions to be assessed
2. A numerical scoring ranging from 1 for a low score to 4 or 5 as top scores
3. Statements, behaviors, or expectations for each dimension being assessed

Rubrics are generally divided into two types: *analytical* and *holistic*. Analytical rubrics are generally more quantitative and address performances broken down into individual tasks or parts. Holistic rubrics are generally more qualitative and consider the entire performance as a whole. The analytical rubric provides science instruction with a consistent standard for each level or stage identified. By using analytical rubrics, students not only can assess their present level but can also become aware of the standards or behaviors they must achieve to advance to the next performance level. By providing the rubric at the same time the task is given, students can see in advance what they must do to perform at an exceptional or proficient level. Teachers find that students strive for higher standards of achievement when they are provided with guidelines for success. The rater, either the teacher or the student (for self-assessment purposes), uses the rubric as a guide in making judgments about the performance of the learner. The rubric, like the portfolio, serves as a starting point for discussing and evaluating the learning process.

Several science rubrics can be found using the Internet. Do a search for the terms *rubric, science,* and *inquiry*. These are four Web sites for sources of science inquiry rubrics:

- http://www.stclair.k12.il.us/services/scilit/Invstrbr.htm
- http://www.stclair.k12.il.us/services/scilit/hlsticrb.htm
- http://www.exemplars.com/science_rubric.html
- http://www.col-ed.org/smcnws/scientific.html

MONITORING CHARTS

Monitoring charts center on observing and recording what students are expected to do during the course of their inquiries. The chart enables the teacher to identify and monitor skills used by students as they investigate solutions to their questions. By observing a predetermined set of behaviors, the teacher can move about the room and observe individual behaviors. These behaviors are noted and checked off on a sheet by using either a *check* + (√ +) for above standard performance, *check* (√) for standard performance or *check* - (√ –) for below standard performance. Teachers can also assign a letter grade or rating for each behavior (E = excellent, G = good, F = fair, N = not observed). Hart (1994) suggests that the teacher, while making class observations, also make informal and anecdotal comments using the following guidelines:

- Observe and monitor all students equitably.
- Observe often and regularly.
- Record observations in writing.
- Note typical as well as atypical behaviors.
- Make multiple observations to ensure reliability.
- Document the date, time, and stage of the lesson.

Figure 7.3 shows a sample inquiry monitoring chart for a scientific inquiry.

CONCEPT MAPS

Concept maps are often used in the beginning of an inquiry lesson to synthesize the aggregate knowledge of the class prior to the start of a lesson. They are also being used as postassessment tools to evaluate the ability of students to connect prior knowledge to new knowledge gained. Concept maps have been used by all levels of teachers, kindergarten through high school (Hein & Price, 1994), and are gaining in use.

A *mealworm concept map* may look like the one shown in Figure 7.4.

In comparing concept maps that were drawn before a lesson with ones drawn afterward, teachers can assess how the students' conceptual understanding has grown as a result of learning opportunities.

SELF-EVALUATIONS

Self-evaluations are a means to collect feedback about how students perceive their individual and group performances. Although students often rate their performances at exceedingly high levels, self-evaluations do provide a window into students' perceptions about how well they did on a science exploration. Self-evaluation also offers students the opportunity to reflect on how they might improve their performances if they were to repeat the task a second time.

Self-evaluations can be used in conjunction with other evaluation methods as an open-ended means of assessment. Form 7.2 is a sample self-evaluation for the mealworm inquiry.

Figure 7.3. Science Inquiry Monitoring Chart

Stage/Behavior	*Investigation #*				
	1	*2*	*3*	*4*	*5*
Exploring					
Makes observations					
Records observations in journal					
Takes careful notes					
Draws illustrations/sketches					
Records "What if" questions					
Stating a question					
Sorts and revises questions					
States an investigation question					
Brainstorms possible solutions					
Identifying a statement to test					
Makes a statement to test					
Records statement					
Designing a procedure					
Brainstorms possible steps					
Arranges steps in sequential order					
Identifies manipulated variable					
Identifies responding variable					
Identifies dependent variable					
Determines materials to use					
Carrying out a plan					
Obtains supplies and materials					
Follows written procedure					
Follows safety guidelines					
Shares/respects ideas with group members					
Assumes responsibility for group role					
Makes constructive contributions to group					
Collecting evidence					
Gathers data					
Makes accurate measurements					
Organizes data in tables or charts					
Plots data on a graph					
Describes relationship between variables					
Draws conclusion; analyzes results					
Determines validity of hypothesis					
Communicating results					
Prepares trifold poster					
Makes contribution to presentation					
Uses appropriate terminology					
Makes eye contact with audience					
Speaks clearly					
Answers questions from audience					
Reflects on investigation					

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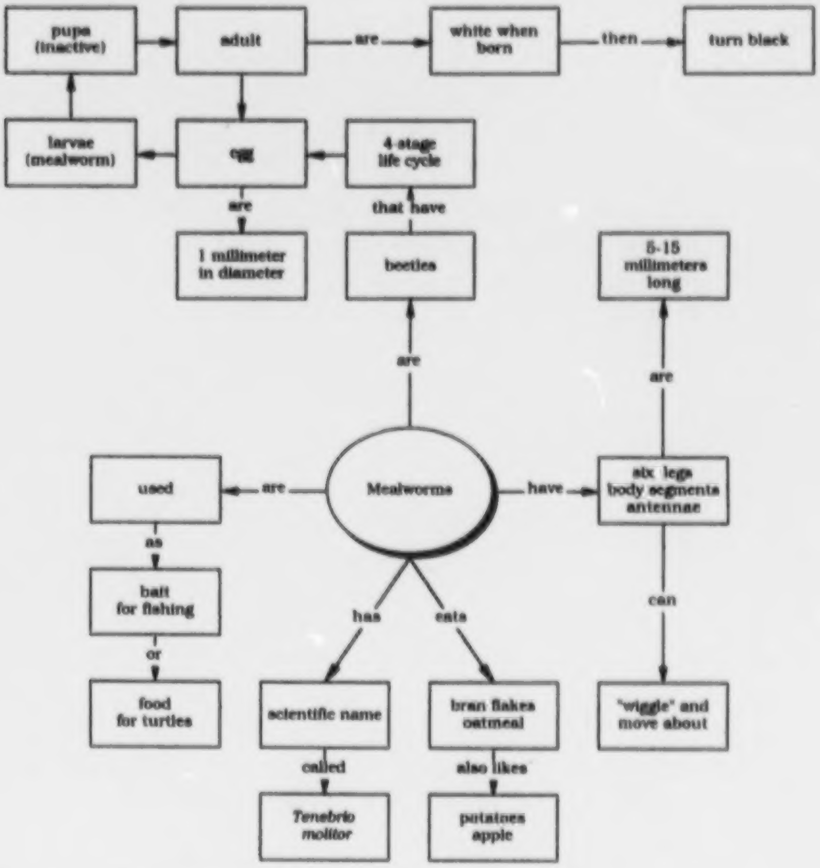
Figure 7.4. Concept Map of Mealworms



CELEBRATING LEARNING

At the conclusion of an inquiry unit, it would be appropriate to celebrate the learning process by awarding students with a diploma certifying them, for example, as "Certified Mealwormologists." Figure 7.5 shows a sample diploma.

SUMMARY OF AN INQUIRY UNIT

Using the 5-E Learning Cycle, the steps of the "Mealworms to Go" inquiry may be summarized as follows:

Engagement

1. Introduce the concept to be learned.
2. Assess prior knowledge.

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FORM 7.2

SELF-EVALUATION FORM FOR THE INQUIRY UNIT: "MEALWORMS TO GO"

Name ______________________________

	Almost Always	*Often*	*Sometimes*	*Rarely*
Engagement				
I handled the mealworms properly.	○	○	○	○
I washed my hands after handling the mealworms.	○	○	○	○
I made good observations and measurements.	○	○	○	○
I made accurate drawings of the mealworms.	○	○	○	○
Exploration				
I followed the procedures in my inquiry plan.	○	○	○	○
I productively participated in the group discussions.	○	○	○	○
I listened to other members of my group and respected their ideas.	○	○	○	○
I did my share of the group work.	○	○	○	○
I used my journal to record my observations and measurements.	○	○	○	○
I used the supplies and materials appropriately.	○	○	○	○
Explanation				
I used many sources to collect information about mealworms.	○	○	○	○
I shared what I learned about mealworms with others in my class.	○	○	○	○
I listened to other members of my group and respected their ideas.	○	○	○	○
Extension				
I shared responsibility during the Mealworm Convention.	○	○	○	○
I made good eye contact during the Mealworm Convention.	○	○	○	○
I projected my voice during the Mealworm Convention.	○	○	○	○

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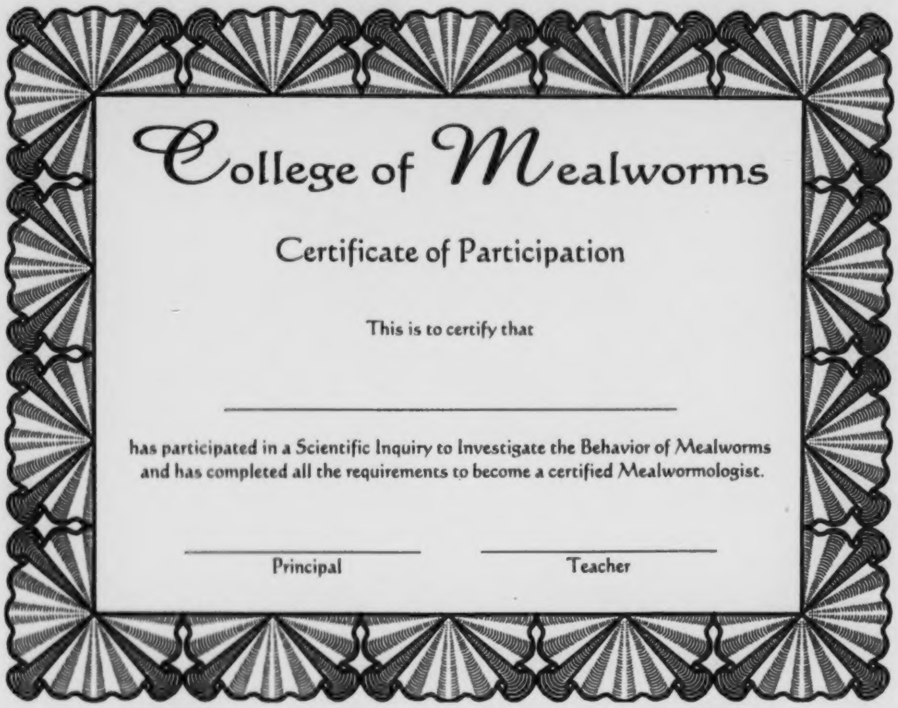
Figure 7.5. Mealworm Award



College of Mealworms

Certificate of Participation

This is to certify that

____

has participated in a Scientific Inquiry to Investigate the Behavior of Mealworms
and has completed all the requirements to become a certified Mealwormologist.

________________ Principal

________________ Teacher

3. Have students share what they know about mealworms with a partner.
4. Make a concept map from what the entire class knows about mealworms.
5. Provide time for students to observe mealworms and record observations in their science journals.
6. Encourage students to write questions to investigate.
7. Sort questions according to whether or not they can be answered through an investigation.
8. Assist students in researching information in the library and on the Internet.

Exploration

9. Assist students in planning out an investigation using the inquiry data sheet.
10. Support students as they gather data, organize their evidence on a chart or graph, look for patterns and relationships, and draw conclusions.

Explanation

11. Provide information through direct instruction or class discussion on the topic being studied.
12. Encourage students to communicate the results of their investigations by holding a "Mealworm Convention."

Elaboration or Extension

13. Introduce the performance task "Mealworms to Go."

14. Have students brainstorm ideas about the container designs.
15. Have students choose the best design and produce the container.
16. Ship the container to the cooperating class.
17. Videotape the opening of the container.
18. Evaluate results.

Evaluation

19. Select one or several methods for assessing what students are expected to know and be able to do as a result of this unit.
20. Award "Mealwormologist" diplomas.

The Learning Cycle is a powerful instructional tool for constructivist and inquiry-based teachers. When integrating inquiry into the Learning Cycle, teachers can provide several opportunities for students to do inquiry-based investigation as part of the Exploration and Extension stages. Consider using the Learning Cycle approach with your next science lesson and plan an inquiry-based investigation as part of either phase on the cycle. You'll see how easily both work together!

8

Skills and Knowledge of Inquiry-Based Teachers

INQUIRY 101

Teachers new to inquiry often ask "How do I become an inquiry-based teacher?" I suggest they start by finding someone who is recognized as being a good inquiry-based teacher and see what he or she does. Take a notepad along, record what the teacher says, how the teacher moves about the classroom, and how he or she respects what the students say. Observe the kinds of learning opportunities the teacher provides to the students. Observe the layout of the classroom. Listen to the interaction between the teachers and the students, the types of questions the teachers pose, and what the teachers says after a student gives an answer. Ask how the teacher uses national, state, and district standards to plan the lesson. Take notes on the type of assessments the teacher uses.

Many of us work with excellent, creative, and inspiring teachers. They are the ones who are truly respected for their ability to engage students in the learning process. Excellent teachers often open their classrooms up for new and inexperienced teachers to observe. When new teachers observe the classrooms of these teachers, they often come away saying "I want to be able to teach like that someday." The situation is similar to an art student going to a museum to see great art. A student must observe and appreciate great works of art to be inspired to set goals and keep striving toward them.

I once read an interesting book about how to play tennis, *The Inner Game of Tennis*, written by a famous tennis coach, W. Timothy Gallwey. After years of giving tennis lessons, Gallwey (1974) came to realize that traditional methods of teaching tennis were not effective for many of his students. He illustrated this point by describing the way most tennis coaches teach new players. Most tennis coaches stress the basic fundamentals of stance and position. They focus on how to position your elbows, how to hold your head, and where to place your feet. Gallwey wanted to try something different. He wanted to teach through *modeling*. To teach someone how to serve, Gallwey demonstrated a "perfect" serve and then had the student picture that serve in his or her mind. Next, the student replicated that same serve. Gallwey wanted the young players to imagine what it looks and feels like to deliver a perfect serve. He didn't wanted his students to be overconcerned about body stance and position. That would come later.

I never became a great tennis player, but I learned a great lesson about teaching science from reading that book. Before teachers get into the details of instruction and strategies about inquiry, they should first have a model or visualization in mind of what they want to do. Details will come later.

IT'S ELECTRIC!

Never underestimate the power of modeling. Modeling the kind of behaviors we want students (or others) to demonstrate is one way of teaching them something new. Several years ago, I attended a friend's wedding reception. After dinner, the disc jockey began playing music, and the wedding party and the guests began dancing. The disc jockey played the "Electric Slide." Because I had never done the "Electric Slide" I just joined in and watched what everyone else was doing. I focused on the person ahead of me and tried to follow what she did. After a few minutes, I had it down and was moving like the rest of them. I didn't need any dance lesson, and I didn't need someone to break down the steps into individual moves. I just observed someone doing it well and tried to model what she was doing.

My point is that finding and observing role models is a great way to start to learn how to do inquiry. Great teachers are credible and model what they believe. If you want to become an inquiry teacher, modeling inquiry is essential to learning how.

There is no secret formula for becoming an inquiry-based teacher. The bottom line is that becoming an inquiry teacher takes time. It also takes a lot of practice, persistence, reading, and reflecting. Everyone goes through just about the same process as they start to develop their inquiry-teaching skills.

YOUR FIRST TRY AT INQUIRY

Your first try at inquiry is usually not your best. But there is no need to dwell on how *bad* your first inquiry lesson might have been. You won't die, your students will survive, and best of all, you get another day to try again. If the first try goes bad, find a quiet place to sit and write down what you think went well and what you would do differently the next time. Make notes about revising your lesson. Make revisions and suggestions for the next time you do that lesson. You'll have another chance to do that same lesson again, only better. That is what second tries are for. Concentrate on what you'll plan to do differently tomorrow. Can you do better at anticipating students' questions? Make certain more materials or equipment are available? Move two kids who can't work well in a group to a different setting? Make your directions more explicit? Remember to save enough time for cleanup and closure? During the second try, have a colleague you trust and respect observe you. Ask this person for feedback and to act as a *reflective friend.* Tell your friend that you are trying to change your instructional style and want feedback on those specific areas.

Teachers exploring new teaching strategies in inquiry can form a support group and meet each month over coffee to discuss and share their ideas. Use the time to critique and reflect on each other's lessons and work. Allow yourself to make mistakes and learn from them. Strive for improvement every time you do the lesson over again. Perfection does not come on the first try.

I recall a story about a high school science teacher (I'll call her Barbara) who gave an inquiry lesson on "the cell" to a class of 25 ninth graders. It failed miserably. To add to the disaster, her mentor was observing her performance. As this person gave Barbara her impression of the lesson, Barbara sat there listening to her comments and feeling completely dejected. Later that night, still distraught, she even considered starting a new career. The next day, Barbara began to rearrange parts of her lesson as her mentor's suggestions rushed through her mind. She rewrote the directions and redesigned the lesson from her students' point of view. It was now in a language they could understand. Three hours later, she had a new lesson. Barbara couldn't wait to try it again.

About now, a little voice whispers in your head. That voice will plant the seed of self-doubt: "Is all this really worth it?" "Why don't you quit all this nonsense and just teach like everybody else does in this school?" "After all, just what are the kids learning anyway?" "Don't you remember what happened during third period? Boy, was *that* a disaster!"

Self-doubt is a natural part of any change process. Don't listen to the voices and don't listen to the cynics down the hall. Trust your instincts! Keep at it. Find that reflective friend, have lunch together, and gain the assurance that you are on the right track. After all, it's your classroom. You can do anything (well, almost anything) you want. You can choose to be a great teacher, or you can choose to be a mediocre teacher. You can also choose to be a boring teacher. It's all up to you. You can either give in to the voices and go back to your old ways—or move ahead. It's your call.

COMMITMENT

If you are seriously thinking of becoming more inquiry oriented, start by making a commitment to doing two or three inquiry-based units a year. Most lessons for the units you're doing have probably already been done. Start by delegating more ownership and responsibility to the students. A good place to start is to have students raise questions and design their own procedures with less emphasis from the teacher or the textbook.

Consider videotaping one of your lessons and analyzing it on your own. Afterward, if you feel confident, show it to someone who also does inquiry learning and ask for an honest response.

Save your videotaped lessons, and as you progress, view them over and over. As you become more comfortable with inquiry-teaching strategies, you will also be able to do a better job analyzing your performance. Saving your prior lessons will also demonstrate how you have been able to progress over the years. You will be able to compare one of your earlier lessons to one you give after 3 or 4 years of implementing inquiry in your classroom. The commitment to inquiry teaching is a reward in itself. Once you start on a journey to become an inquiry teacher and see its importance in student learning, you will probably never go back to the traditional ways of teaching again.

AN INQUIRY RUBRIC

A rubric is a set of guidelines used to provide an assessment of a particular performance or task. Rubrics are commonly used when you want to identify performance at various levels of proficiency and identify areas for improvement. In this chapter, we use a rubric to assess and monitor your present level and progress in becoming an inquiry-based teacher.

Like other rubrics, the inquiry rubric in this chapter contains three features: (a) the subsets or dimensions to be assessed, (b) a rating scale, and (c) statements, behaviors, or expectations for each of the criteria at each level being assessed. By using the inquiry rubric, you can assess your present level of teaching through inquiry and become aware of the standards or behaviors necessary for advancing to the next level of performance.

To assess your performance, begin by asking a colleague familiar with inquiry or someone in your support group to observe you teaching an inquiry-based lesson or unit. If possible, videotape the lessons so you and your partner can view it together and discuss particular points of the lesson in comparison to the rubric. The use of the video will serve as a point of departure for a discussion and provide specific evidence in analyzing your lesson. You may choose to schedule a preconference with your observer before your lesson. The purpose of the preconference is to make the observer aware of your lesson or unit objectives. As an observer, I prefer not to know ahead of time what the unit is about. I prefer to go into a classroom and observe a lesson knowing what the students know. If I'm confused as to the focus of the lesson in the first few minutes, the students probably are too.

During the lesson, your partner will circle the behaviors listed on the inquiry rubric that he or she noted during the lesson. At the end of the observation, don't be surprised to see behaviors at various stages on the grid. We often demonstrate different skills at different levels. During the postconference meeting, you can discuss the behaviors that were noted and try to find a pattern in the responses. Are some areas at a different stage than others? How would this demonstrate your strengths and weaknesses for each area?

As you use the inquiry rubric, you will find that not all the areas are observable during a classroom lesson but may be assessed through reflection and discussion. Areas such as curriculum and professional development will have to be assessed this way. In any event, the rubric serves as a starting point for you to assess your level of performance and to identify what behaviors you need to improve on to move to the next level.

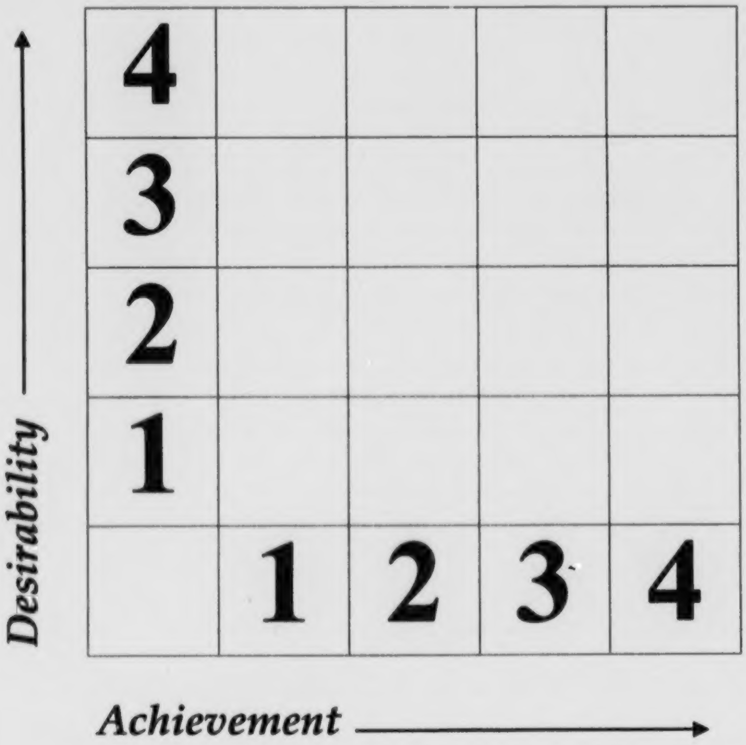
It is important to remember that the use of rubrics is still very subjective and open to judgment. The purpose of the inquiry rubric is not to be able to say that you are at the transitioning level or at the practicing level. Rather, it serves as a springboard to initiate engaging discussion on the components of an inquiry lesson and to reflect on your ability to analyze an inquiry-based lesson.

Table 8.1 (at the end of this chapter) shows a rubric for becoming an inquiry-based teacher. Due to the length and detail of the inquiry rubric, the first time you may choose to focus on two or three subsets in one observation. Then, gradually increase the number of subsets to focus on in subsequent observations.

AN INQUIRY SELF-ASSESSMENT SURVEY

You can also gain an understanding of your level of competency of inquiry through a self-assessment survey. The Inquiry Self-Assessment Survey was adapted from the National Science Teachers Association's (NSTA) *Guidelines for Self-Assessment* (1978). The survey lists statements about inquiry-based instruction that align with the inquiry rubric. You will identify responses for two dimensions: desirability and achievement (see Figure 8.1). For each of the statements in the survey, identify a rating for each dimension as follows:

Figure 8.1. Sample Survey Grid



Desirability
- 4 = Very good desirability, of high interest and/or need
- 3 = Good desirability
- 2 = Fair desirability
- 1 = Unimportant or undesirable

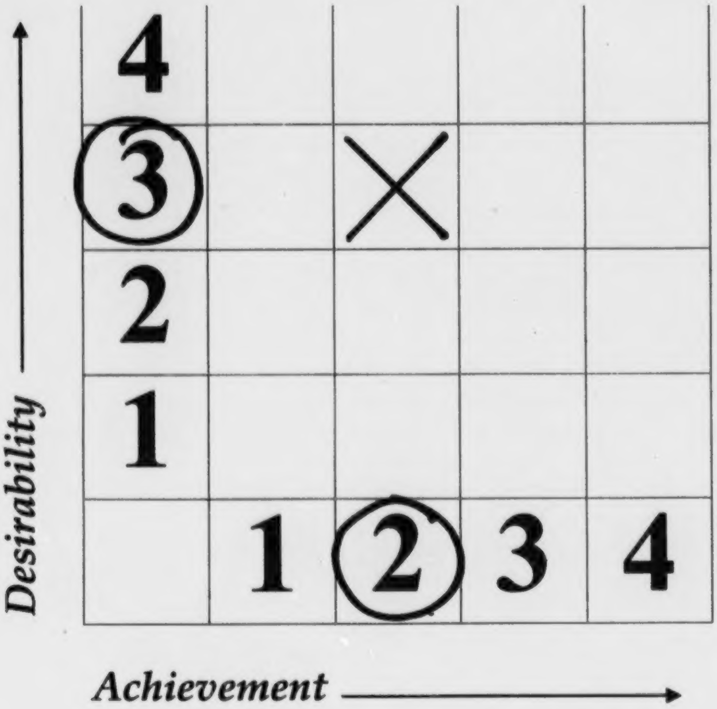
Achievement
- 4 = Very good achievement, of high accomplishment and/or practice
- 3 = Good achievement
- 2 = Fair achievement
- 1 = No achievement

Using the matrix corresponding to a numbered statement, circle the level (1-4) on the horizontal axis (desirability) and the vertical axis (achievement) that best matches your response to the statement. Then, place an X in the appropriate box that corresponds or intersects the levels for that statement, as shown in Figure 8.2.

For example, 1.1: I provide lessons where students explore their ideas from questions that interest them.

Now, turn to Resource C. You will find the set of matrices for each category. Follow the same procedure for each statement in the following eight categories by placing an X in the appropriate box that corresponds to your answer for that statement.

Figure 8.2. Sample Survey Grid



1. Curriculum
   1.1. I provide lessons in which students explore their ideas around questions that interest them.
   1.2. I provide resources and manipulatives to students to stimulate students' curiosity and thinking skills.
   1.3. I emphasize process skill development as part of my lessons.
   1.4. I plan and design my curriculum according to *National Science Education Standards.*
   1.5. I design my curriculum with student-centered lessons in which students plan their own investigations.
   1.6. Problem solving plays a major role in my curriculum planning.
   1.7. My curriculum uses various primary sources of information.
   1.8. The content of my curriculum is structured around learning concepts that are relevant and based on students' personal experiences.

2. Lesson Presentation
   2.1. My role as a teacher is that of a facilitator.
   2.2. My lessons provide opportunities for students to solve problems.
   2.3. I provide opportunities for students to design the procedures and data tables for their own investigations.
   2.4. My units begin with a highly motivating problem, question, or demonstration.
   2.5. I use the Learning Cycle to prepare lessons.

2.6. I prepare lessons in which science is integrated with other subject areas.
2.7. My lessons begin with assessing students' prior knowledge.

3. Communication
   3.1. I provide opportunities for students to share their ideas and information in class.
   3.2. During a lesson, I move throughout the room, speaking from different areas of the room.
   3.3. When speaking to students in small groups, I usually kneel down or sit at a student desk to make eye-to-eye contact with them.
   3.4. I consistently provide praise and positive reinforcement when students give correct answers or make contributions to class discussions.
   3.5. I provide opportunities for students to talk and share their ideas with each other.

4. Engagement of Students
   4.1. In my room, students are engaged in investigations, discourse, and reflection.
   4.2. I encourage students to be self-directed learners.
   4.3. I frequently plan lessons that are both hands-on and minds-on.
   4.4. I consistently solicit information, ideas, and thoughts from students.
   4.5. I encourage cooperative learning relationships among students.
   4.6. Before beginning an activity, I have students review and repeat the purpose and procedures to ensure that everyone knows what is expected of them.
   4.6. I encourage students to act as "study buddies" and peer tutors for each other.

5. Classroom Organization
   5.1. Many supplies and materials are readily available for students to access on their own.
   5.2. I provide classroom time for student investigations.
   5.3. I promote dialogue among my students.
   5.4. I encourage students to make decisions about their own work.
   5.5. I use constructivist teaching strategies in my classroom.
   5.6. I encourage students to make decisions about the arrangement of the classroom.
   5.7. My lessons are frequently designed around cooperative learning groups.

6. Questioning Skills
   6.1. I pose various levels of questions to students.
   6.2. I consistently ask open-ended questions to encourage students to think at higher levels.
   6.3. I often follow up students' responses to questions with extension questions.
   6.4. I consistently value students' opinions and responses.
   6.5. I consistently use wait-time strategies.
   6.6. I use probing statements, prompts, and redirectioning questions to solicit students' understanding.

7. Assessment Procedures
   7.1. I use authentic assessments to evaluate student progress.
   7.2. I have students use journals to record and organize their notes from class discussions and their scientific investigations.

7.3. I have students keep their science work in portfolios for reflection and discussion.

7.4. I regularly observe and assess students' attitudes in science as part of my evaluation of their progress.

7.5. I regularly observe and assess critical thinking skills in science as part of my evaluation of the students' progress.

8. Professional Development

8.1. I share my inquiry-based units with other interested teachers.

8.2. I am part of a support group to share ideas on teaching through inquiry.

8.3. I use *NSES* as part of my professional development plans.

8.4. I regularly read periodicals and books on inquiry and constructivism.

8.5. I have attended a workshop or seminar on inquiry or constructivism in the past 2 years.

EVALUATING YOUR RESPONSES

After filling out a matrix for each statement in the survey, you are ready to compile your responses for each of the eight categories. Each category has its own summary matrix (see Resource B). For the "Curriculum" category, place the number of that statement in the corresponding box in the summary matrix (see Figure 8.3).

Figure 8.3. Sample Survey Grid Completed

1. Curriculum

4	1.8	1.4 1.6	1.2 1.3	
3	1.5	1.1 1.7		
2				
1				
	1	**2**	**3**	**4**

Desirability →

Achievement →

Repeat the procedure for each of the other seven categories.

Each matrix is made up of four areas (see Figure 8.4). Look at the number of statements in each of the four areas of the matrix.

Area 1. Responses in this area indicate high desirability and low achievement. Statements in this quadrant are areas you indicated a need to improve on. These statements will become the focus of your professional development in the months and years ahead.

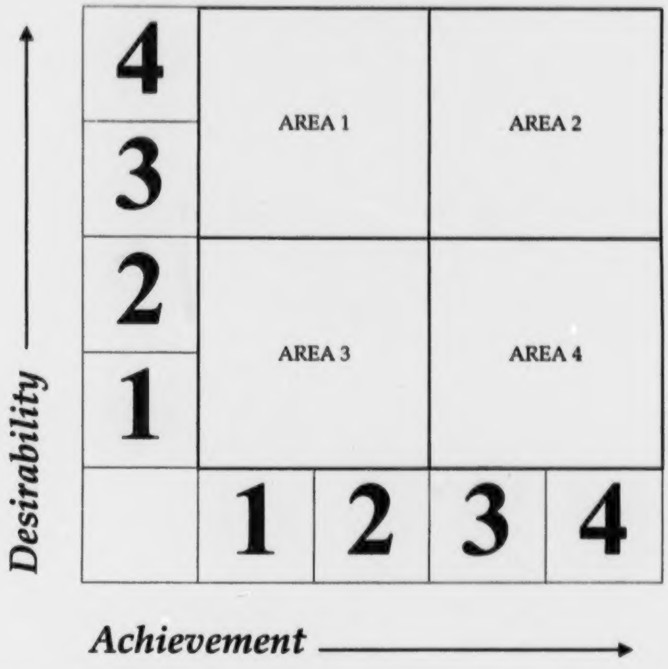
Area 2. Responses in this area indicate high desirability and high achievement. Statements in this quadrant are areas of your perceived strengths. These areas will require your continued maintenance.

Area 3. Responses in this area indicate low desirability and low achievement. Statements in this quadrant are areas of nonimportance for you. Center your efforts on improving in Area 1. If you take the survey again a year from now, see if any statements that were previously in Area 3 have now moved to Area 1. If so, that will be the time to focus on them. It is better to focus on one or two areas rather than to take on too much.

Area 4. Responses in this area indicate low desirability and high achievement. Statements in this quadrant are not applicable because they may indicate that you have skills you don't care about.

You now can use the self-assessment survey to plan your professional development needs by identifying the responses listed in Area 1. Brainstorm possible actions and solutions to improve your knowledge and skills in Area 1 for one or two of the eight categories.

Figure 8.4. Sample Survey Grid Showing Four Areas



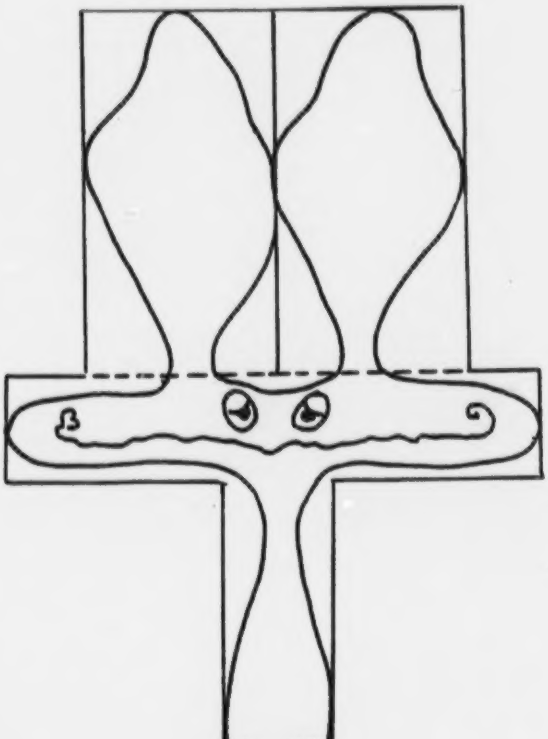
BUGS-O-COPTERS

In becoming an inquiry-based teacher, a central focus is your ability to raise your own personal capacity to do inquiry. Building the capacity and ability for teachers to do inquiry is an essential goal of this book.

Many teachers may be familiar with *Bugs-o-Copters.* Begin an exploration by making a photocopy of the short-eared Bugs-o-Copter found in Resource C (if possible, copy it on heavier, 24-lb weight paper) and cutting it out as shown in Figure 8.5.

Figure 8.5. How to Cut Bugs-O-Copter

Directions:
1. **Cut along the outside solid lines.**
2. **Cut straight down between the two ears to the dotted line.**



Now, bend one ear forward at the crease (dotted line) and bend one ear back. The ears should be perpendicular to the body. Attach a paper clip at the "feet," or bottom, of your Bugs-o-Copter and hold it as high as possible with an outstretched arm. For added height, you might want to stand on a chair. Release Bugs-o-Copter and observe what happens. Try it several times. What did you observe? Did the Bugs-o-Copter react the same time for each trial? Record your observations on a separate sheet of paper.

Next, photocopy and cut out the long-eared Bugs-o-Copter found in Resource D. Compare the two Bugs-o-Copters. What do you observe? You may notice that both the Bugs-o-Copters are the same except for ear length. Fold the ears along the crease as you did with the short-eared one. Make a prediction: How will the length of the ears affect the rate of falling? Will the long-eared Bugs-o-Copter fall faster or slower? How does the length of the ears affect the rate of spinning? Will the long-eared Bugs-o-Copter spin faster or more slowly than the short-eared Bugs-o-Copter? Choose a question to investigate and record your prediction on a sheet of paper. Because you are going to test your prediction, the statement can be written as a hypothesis.

Before testing your hypothesis, think of how you are going to design your investigation. This is an important part of any inquiry. Students often go directly into testing before identifying the procedure. The procedure may easily come to mind, but this time we want to write it down on paper first.

Which variable will you test (the manipulated or the independent variable) in your investigation? Which variables will stay the same (the controlled variables)? Which variable will be used to measure your results (the responding or the dependent variable)? After you have thought about all these questions, you are ready to test your hypothesis.

By investigating the effect of the ear length on the rate of falling, you probably identified ear length as the manipulated or independent variable—in other words, what you changed on purpose. You also probably kept all other variables the same, such as dropping the Bugs-o-Copter from the same height, the same way, under the same conditions, and placing only one paper clip on each Bugs-o-Copter at the same location. These are called the controlled variables. These variables will stay the same with both Bugs-o-Copters. This way only one variable, the length of the ears, will affect the outcome of the investigation. In the first question, the time it took the Bugs-o-Copter to hit the floor is the responding or dependent variable. That is what we look for or measure to see if the ear length makes any difference. In the second question, the number of spins the Bugs-o-Copter makes is the responding or dependent variable.

Drop both the short-eared and the long-eared Bugs-o-Copters at the same time. What happened? Record your observations.

HOW MANY "WHAT IF" AND "I WONDER" QUESTIONS CAN YOU THINK OF?

On the basis of that initial Bugs-o-Copter exploration, what other questions come to mind that you can investigate? Think of several "What if" or "I wonder" questions to raise. How many questions can you come up with? Take a few minutes and write all of them down on your paper. Write as many questions as come to mind.

How many questions were you able to think about that you could test using the Bugs-o-Copter? One? Five? More than five? This is actually a test. It's a test of your *I.Q.*—your *Inquiry Quotient*. The more questions you are able to raise (including designing and carrying out the procedures), the higher your Inquiry Quotient. Some teachers do the

Bugs-o-Copter investigation and can't think of any questions to test. Other teachers will think of lots of possible questions to investigate. Your questions may have included the some of the following:

Does the number of paper clips affect the falling rate?

What would happen if I place the paper clip on the ears of the Bugs-o-Copter?

Does the thickness of the paper affect how the Bugs-o-Copter will spin?

I wonder, what would happen if I made a Bugs-o-Copter out of poster board instead of paper?

What if I cut out the outline (shape) of the ears?

Does the shape of the ears affect how the Bugs-o-Copter falls?

What if I put the paper clips in a different location?

How can I get both the short-eared Bugs-o-Copter and the long-eared Bugs-o-Copter to hit the floor at the same time?

What if I change the direction the ears are folded?

How would cutting slits in the ears affect the spinning?

Will the way the ears are folded affect how the Bugs-o-Copter will spin?

How can I make the Bugs-o-Copter spin in the opposite direction?

Which Bugs-o-Copter, the short-eared or long-eared, makes more spins before hitting the floor?

Would the Bugs-o-Copter spin in the opposite direction in the Southern Hemisphere from the way it spins in the Northern Hemisphere?

Now that you have lots of questions to investigate, your next step is to design a procedure, carry out a test, gather and organize data, and draw a conclusion based on the evidence for as many questions as possible.

BECOMING AN INQUIRY TEACHER

Many teachers admit that the journey in becoming an inquiry teacher is a very personal experience. We make the journey in different ways, by constructing our own paths to instructional renewal and reform. Your journey may begin by assessing your prior experiences in becoming a teacher. Some teachers may have been educated with little or no experience in testing out their own ideas. For them, the shift must seem like a climbing a huge mountain. For others, moving toward an inquiry approach is just good teaching. Thus the paradigm shift is different for different teachers.

Becoming an inquiry teacher requires creating and sustaining reflection practices and discourse with other teachers. As Sergiovanni (1996) puts it, "good teaching requires that teachers reflect on their practice, and create knowledge in use as they analyze problems, size up situations and make decisions" (p. 151). For that reason, teachers need to develop a network to offer encouragement and support. Inquiry support groups encourage teachers to share their lessons, accomplishments, and frustrations. A local college or university science education department can be a source for developing and facilitating a teacher study and support group. Finally, the school and the administration must demonstrate trust that teachers can make the appropriate curricular decisions to bring inquiry-based instructional strategies and change to the classroom level. Lack of support from peers and administrators has often discouraged many teachers from building their capacity to develop inquiry-centered classrooms.

Regardless of how you plan to start to increase your ability to teach through inquiry, my best advice is not to do it alone. Seek out a friend or group of people who shares the same values and beliefs about teaching that you do. Ongoing conversation with colleagues will help you to enhance your skills and development.

Table 8.1. Rubric for Becoming an Inquiry-Based Teacher

Curriculum			
Traditional Approach	*Exploring Inquiry*	*Transitioning to Inquiry*	*Practicing Inquiry*
• Student knowledge is solely based on mastery of facts and trivial information.	• Student knowledge is based on mastery of facts and science process skills.	• Student knowledge is based on mastery of facts, science process skills, and problem-solving skills.	• Student knowledge is based on ability to apply facts and science process skills to solve problems and make connections to new situations.
• Curriculum is teacher-centered and based on prescribed activities with anticipated results.	• Curriculum allows for some flexibility for investigations according to the interests of the students.	• Curriculum allows for flexibility of investigations and units of study according to the interests of the students.	• Curriculum is student centered and provides flexibility for students to design and carry out their own investigations.
• Teacher is not aware of *NSES*[a] and does not use national standards to plan curriculum.	• Teacher is aware of *NSES* but does not use national standards to plan curriculum.	• Teacher is aware of *NSES* and occasionally uses national standards to plan curriculum.	• Teacher is aware of *NSES* and consistently uses national standards to plan curriculum.
• Curriculum in based on single textbook.	• Curriculum uses multiple textbooks and resources.	• Curriculum uses multiple textbooks, Internet, and other software resources.	• Curriculum uses multiple textbooks, Internet, and other software and primary resources.
• When curriculum is not mandated, it is based on teacher's interest.	• When curriculum is not mandated, it is based on teacher's interests; students sometimes choose topics.	• When curriculum is not mandated, it is based on interests of teacher; students often choose topics.	• When curriculum is not mandated, it is based on flexibility between teacher needs and student interests.
• Curriculum is based on single, narrow science topic only.	• Curriculum occasionally integrates relevant topics of science with math and technology.	• Curriculum frequently integrates science with math and technology of relevance to students, also according to students' personal experience.	• Curriculum is theme based and integrates science with math, technology, and other subjects of relevance to students, also according to students' personal experience.

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Lesson Presentation			
Traditional Approach	*Exploring Inquiry*	*Transitioning to Inquiry*	*Practicing Inquiry*
• Teacher is center of lesson.	• Teacher is center of lesson, sometimes acts as facilitator.	• Teacher is center of lesson, frequently acts as facilitator.	• Teacher consistently acts as effective facilitator and coach.
• Teacher frequently lectures and uses demonstrations and activities to verify science information.	• Teacher usually lectures and does demonstrations and activities to explain science information.	• Teacher occasionally lectures and uses demonstrations and activities to reinforce science concepts.	• Teacher occasionally lectures and uses investigations to apply science concepts.
• Teacher lectures first and then provides students with activity or lab.	• Teacher attempts to use 5-E Learning Cycle approach.	• Teacher frequently uses 5-E Learning Cycle approach with satisfactory success.	• Teacher regularly and effectively uses 5-E Learning Cycle approach, assesses prior knowledge.
• Teacher uses only demonstrations and structured activities.	• Teacher uses demonstrations and attempts open-ended activities.	• Teacher uses demonstrations and open-ended activities and occasionally attempts teacher-initiated and student-initiated inquiries.	• Teacher uses all stages of inquiry grid and consistently provides teacher-initiated and student-initiated inquiries.
• Teacher plans only whole-class instruction.	• Teacher plans whole-class instruction but occasionally uses small-group instruction.	• Teacher plans whole-class instruction and regularly uses cooperative learning groups.	• Teacher effectively plans for whole-class instruction as needed and frequently uses cooperative learning groups.
• Teacher has difficulty with unexpected results.	• Teacher begins to accept unexpected results.	• Teacher easily accepts unexpected results.	• Teacher accepts and anticipates unexpected results.

continued

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Table 8.1. *Continued*

Communication			
Traditional Approach	*Exploring Inquiry*	*Transitioning to Inquiry*	*Practicing Inquiry*
• Teacher rarely allows students to share information with each other through small-group discussions and dialogue.	• Teacher occasionally allows students to share information with each other through small-group discussions and dialogue.	• Teacher frequently expects students to share information with each other through small-group discussions and dialogue.	• Teacher consistently expects students to share information with each other through small-group discussions and dialogue.
• Teacher speaks mainly from the front of the room.	• Teacher usually speaks from the front of the room and occasionally moves about.	• Teacher frequently moves about the room, speaking from different areas.	• Teacher effectively moves about the room, speaking from different areas to monitor and enhance learning.
• Teacher communicates by standing above and over students.	• Teacher occasionally communicates to students by kneeling by or sitting on a student seat to make level eye contact.	• Teacher frequently communicates to students by kneeling by or sitting on a student seat to make level eye contact.	• Teacher consistently communicates to students by kneeling by or sitting on a student seat to make level eye contact.
• Teacher provides little positive reinforcement.	• Teacher provides occasional positive reinforcement.	• Teacher provides frequent positive reinforcement.	• Teacher provides frequent and equitable positive reinforcement.
• Communication is mostly from teacher to student but rarely from student to student.	• Communication is usually from teacher to student but occasionally from student to student.	• Communication is occasionally from teacher to student but frequently from student to student.	• Communication effectively varies from teacher to student and from student to student according to the situation.
• Expectations are not clearly stated.	• Expectations are occasionally not clearly stated.	• Expectations are usually clearly stated and understood.	• Expectations are clearly stated and understood.

Engagement of Students			
Traditional Approach	*Exploring Inquiry*	*Transitioning to Inquiry*	*Practicing Inquiry*
- Teacher engages students through oral questioning and discussions.	- Teacher engages students through oral discussions and open-ended questions.	- Teacher engages students through open-ended discussions and investigations.	- Teacher engages student through open-ended discussions, investigations, and reflections.
- Minimal student engagement.	- Occasional student engagement.	- Frequent student engagement.	- Frequent self-engagement by students.
- Students are mostly passive but teacher uses some hands-on activities.	- Students are occasionally active; teacher uses hands-on activities but attempts open-ended investigations.	- Students are mostly active; teacher uses hands-on activities but attempts open-ended investigations and encourages student-directed explorations.	- Students are consistently active; teacher uses hands-on and minds-on activities that encourage open-ended, student-initiated investigations and explorations.
- Teacher rarely solicits information from students.	- Teacher occasionally solicits information from students.	- Teacher frequently solicits information from students.	- Teacher frequently and effectively solicits information from students.
Classroom Organization			
- Student desks are arranged in rows with seating assigned by teacher; focus toward front of class; teacher desk in front center of class.	- Student desks are usually arranged in rows or in groups assigned by teacher for occasional group work; teacher desk to the side of classroom.	- Student desks are arranged in groups assigned by teacher and students for cooperative learning groups; teacher desk at side or in back of classroom.	- Teacher and students share decisions around room and seating arrangements to maximize student interactions, work, and discussions.
- Supplies and materials are locked away; teacher permission is needed for students to access items.	- Some supplies and materials are readily available for students to access on own; teacher permission needed for students to access certain items.	- Many supplies and materials are readily available for students to access on own; teacher permission needed for students to access certain items.	- Most supplies and materials are readily available for students to access on own; teacher permission needed for students to access certain items.
- Classroom does not contain centers or areas for students to work independently; room arrangement remains the same for entire school year.	- Classroom occasionally contains centers; room arrangement changes occasionally.	- Classroom regularly contains centers and areas for independent work; room arrangement changes occasionally.	- Classroom contains centers and areas for students to work or read independently; room arrangement changes regularly.
- Walls are mostly bare with a few commercially made posters displayed.	- Posters and some student work displayed on walls.	- Some posters, but mostly student work displayed on walls.	- Walls are filled with work representing all students in the class.

continued

Table 8.1. *Continued*

Questioning Skills			
Traditional Approach	*Exploring Inquiry*	*Transitioning to Inquiry*	*Practicing Inquiry*
• Teacher asks mostly low-level, recall, and knowledge-level questions.	• Teacher asks recall and comprehension-level questions, attempts application and evaluation-level questions.	• Teacher poses higher-level and open-ended questions.	• Teacher uses all levels of questioning and adjusts level to individual students.
• Teacher uses questions to impart knowledge and solicit a desired response from students.	• Teacher uses questioning skills to initiate discussion.	• Teacher uses questioning skills to assess prior knowledge and initiate interactions between teacher and students and students and students.	• Teacher uses questioning skills to assess prior knowledge, facilitate discussions, and construct knowledge.
• Teacher leads students to answer questions correctly, provides correct answer.	• Teacher leads student to answer questions correctly, attempts prompting strategies.	• Teacher frequently uses probing, prompting, and redirectioning techniques.	• Teacher consistently uses probing, prompting, and redirectioning techniques.
• Teacher rarely asks open-ended questions.	• Teacher sometimes attempts to pose open-ended questions.	• Teacher frequently poses open-ended questions.	• Teacher consistently and effectively uses open-ended questions.
• Teacher does not use wait-time strategies.	• Teacher occasionally uses wait-time strategies.	• Teacher frequently uses wait-time strategies.	• Teacher consistently and effectively uses wait-time strategies.
• Teacher follows up students' answers by repeating student answer, saying "Okay," or going on to next question.	• Teacher attempts to follow up students' answers with positive reinforcement before going on.	• Teacher frequently provides praise and positive reinforcement and follows up students' answers with additional probing questions.	• Teacher consistently provides praise and positive reinforcement and follows up students' answers with additional probing and engaging questions.
• Teacher provides answers when students cannot answer questions.	• Teacher attempts rephrasing techniques when students cannot answer questions.	• Teacher frequently uses prompts and rephrasing techniques when students cannot answer questions.	• Teacher consistently and effectively uses prompts and rephrasing techniques when students cannot answer questions.

Assessment Procedures			
Traditional Approach	*Exploring Inquiry*	*Transitioning to Inquiry*	*Practicing Inquiry*
• Teacher frequently uses dittos and worksheets to assess learning; students record data on teacher-designed lab sheets.	• Teacher reduces use of dittos and worksheets to assess learning; teacher attempts having students record data on student-designed lab sheets.	• Teacher seldom uses dittos and worksheets to assess learning; students record data on student-designed lab sheets and/or journals with limited success.	• Teacher seldom uses dittos and worksheets to assess learning; students record data on student-designed lab sheets and/or journals with complete success.
• Teacher mostly uses objective-type testing.	• Teacher uses objective testing and attempts to implement authentic assessment.	• Teacher varies assessment to include objective testing, portfolios, rubrics, and other authentic assessments.	• Teacher consistently and effectively uses assessment to include objective testing, portfolios, rubrics, and authentic assessments.
• Teacher assesses students based on content information only.	• Teacher assesses students based on content and science process skills.	• Teacher assesses students based on content, science process skills, and problem-solving skills.	• Teacher assesses students based on content, science process skills, problem solving skills, and scientific attitude.
Professional Development			
• Professional development includes instruction on content topics.	• Teacher reads books on inquiry-based instruction.	• Teacher takes workshops or college-level courses on inquiry-based instruction, participates in inquiry discussion groups.	• Teacher does workshops and/or writes articles on inquiry-based instruction.
• Teacher is not aware of *NSES*.	• Teacher is familiar with but does not use *NSES*.	• Teacher frequently uses and cites *NSES* in teaching.	• Teacher consistently uses *NSES* as part of teaching and professional development.
• Teacher participates in one-day workshops based on current topics.	• Teacher occasionally participates in ongoing university-sponsored inquiry workshops and seminars.	• Teacher regularly participates in ongoing university-sponsored inquiry professional development sessions and seminars.	• Teacher participates in ongoing inquiry by working with local or university level scientists or by developing original inquiry investigations.
• Teacher is not concerned with learning about inquiry pedagogy.	• Teacher attempts to use Internet resources, videos, software, and CD-ROMs to search for inquiry articles and best practice pedagogy.	• Teacher regularly uses Internet resources, videos, software, and CD-ROMs to search for inquiry articles and best practice pedagogy.	• Teacher frequently uses Internet resources, on-line discussions, videos, software, and CD-ROMs to enhance practice of inquiry pedagogy.
• Teacher works as an individual.	• Teacher works with another teacher to share inquiry strategies and activities.	• Teacher works in collaboration with others to develop and share inquiry strategies.	• Teacher works in collaboration with others in study-group sharing units, articles, and success stories.

a. *NSES* stands for *National Science Education Standards* (National Research Council, 1996).

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9

Using Questioning Skills in Inquiry

QUESTIONS: THE LANGUAGE OF INQUIRY

Children naturally ask lots of questions. When children ask questions, they are pondering new phenomena and seeking to create meaning from their experiences. In science, questions foster children's natural curiosity and guide them in making observations and inferences about their investigations. In constructivist classrooms, teachers ask questions to assess children's understanding and point of view on topics or concepts being studied. In an inquiry lesson, questions open the door to a child's mind and imagination. In this chapter, we explore two types of questions. The first are the type students raise as part of their inquiry investigations. The second are verbal questions teachers pose to students during lessons or discussions. Teachers cannot underestimate their need to develop good questioning skills. Both kinds of questions are essential in developing inquiry-centered classrooms. When used properly, questions can access prior knowledge, encourage explorations, and engage students in critical thinking.

In Chapter 2, we read about a fourth-grade class exploring the properties of ice. Although this was their first opportunity to do an actual investigation, the children had no trouble thinking of questions to investigate:

How long does it take water to freeze?
What are the "bubbles" in the ice hand?
Why does the ice hand melt in the water?
Why do the fingers get pointy when they melt?
Why does water expand while freezing?
Why is the ice smooth in some spots and rough in others?
How do icebergs form?

I wonder if the ice hand would melt faster if we stirred the water in the pan?
Why does ice float in water?
Does cold ice melt more slowly in cold water than in warm water?
Why is the ice white in the thick part and clear in the thin part?

WHY YOU CAN'T INVESTIGATE A "WHY" QUESTION

When students raise questions during an inquiry lesson, it is important for the teacher to distinguish between information- and investigation-type questions. The questions above consist of both information questions, which require a scientific explanation, and investigation questions, which can be tested. Generally, questions beginning with "Why" are information questions and require an explanation for an answer. For that reason, we generally don't investigate using an information question starting with "Why."

Investigation questions, on the other hand, can be investigated and tested. Investigation questions generally begin with "Does," "How can," "How come," "What if," or "I wonder." Different phrasing indicates different purposes. In the ice hand inquiry, it was important to determine (a) which questions could be answered only by doing further research in the library or by asking an expert and (b) which questions had to be revised and rewritten to change an information question to an investigation question. A good investigation question

1. Leads the student to think of solutions to solve the question
2. Invites a statement to be tested
3. Leads to new information that the student did not know prior to asking the question
4. Relates and applies to real-world situations beyond the classroom

During the ice hand investigation, the teacher sorted all the student questions into three groups: (a) questions ready for investigating, (b) questions needing revision, and (c) questions that needed an expert to answer (see Figure 9.1).

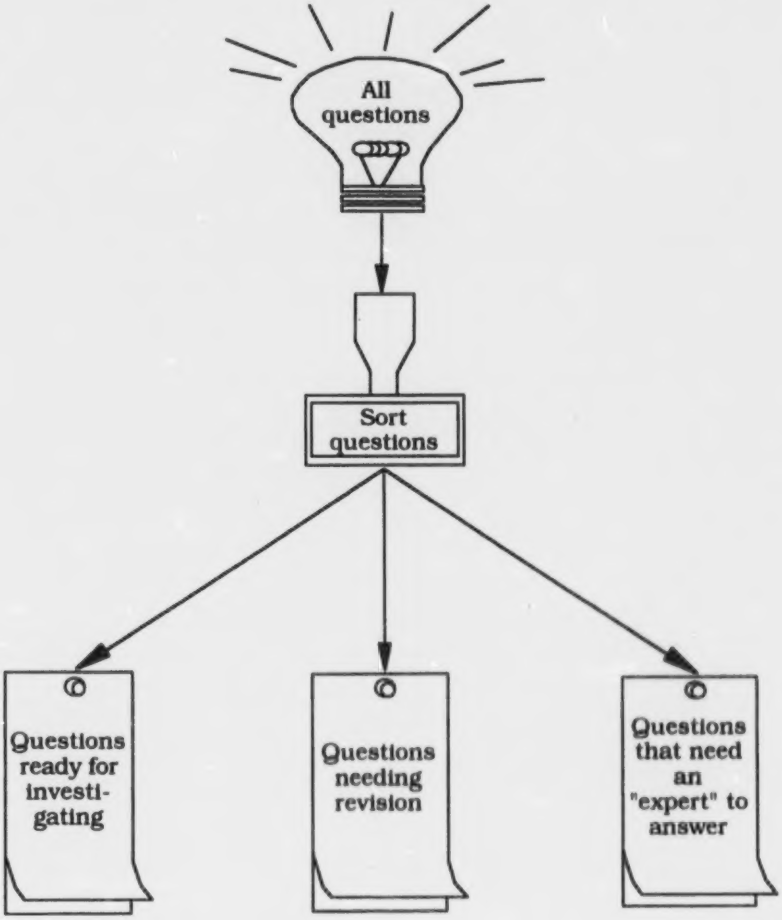
An information question raised by a student was "Why do the thin fingers melt faster than the palm?" Although this is an interesting question, the question needs to be reworded into an investigation question, such as "How does the mass (size or surface area) of the ice cube affect the melting rate?" By rewording the question from "Why" to "How does," the student has a starter question that leads to an investigation.

CLASSROOM QUESTIONS

Now, let's turn to the teacher posing questions during a classroom discussion. Teachers pose questions in an inquiry-centered classroom for the following reasons:

- To engage and motivate in conversation and discussion
- To provide direction to the conversation and discussion
- To assess students' prior knowledge
- To uncover students' misconceptions
- To stimulate and challenge thinking
- To focus, clarify, or guide the discussion

Figure 9.1. Sorting Students' Questions


All questions
Sort questions
Questions ready for investigating
Questions needing revision
Questions that need an "expert" to answer

- To prompt a student to a particular answer
- To process information
- To have students defend a position
- To keep students on task
- To pose problems and guide problem solving
- To seek solutions to problems
- To assess student progress
- To prepare for an upcoming quiz or test
- To reflect and review material of a lesson

Questions are an essential part of a teacher's lesson. Some teachers ask as many as 200 to 300 questions a day! Posing questions to students is an essential aspect of teaching, but just firing off a lot of questions does not necessarily make for a good lesson. Image a discussion led by a middle school science teacher. The teacher is standing at the front of a room of 24 sixth graders. His lesson plan includes using a series of questions to guide a lesson on nutrition. The lesson begins with the teacher passing out crackers and having the students place them in their mouth and chew them. (Teacher and student names are fictitious.)

Mr. Poole: Okay. The first question I would like to ask is, what's happening to the cracker as it enters your mouth? Does anyone know? Can anyone tell me? Angela?

Angela: It's getting chewed.

Mr. Poole: Okay. It's getting chewed. Anything else?

Angela: It's going to your stomach.

Mr. Poole: Okay. Before we get to the stomach, what's happening in your mouth? Ryan, do you know?

Ryan: There's that spit stuff working on it. [Class laughs]

Mr. Poole: That's called saliva, Ryan.

Ryan: Yeah, saliva, that's what I meant.

Mr. Poole: Yes, saliva moistens the cracker. Then what happens? Anyone?

Tomeka: It goes to your stomach?

Mr. Poole: No, before that.

Tomeka: It goes down your esophagus?

Mr. Poole: Right, your esophagus. What about the esophagus? What happens after the esophagus? Anyone know? How about you, Harold?

Harold: Your stomach?

Mr. Poole: Right, your stomach. What goes on there? [Pointing to Ginny]

Ginny: It breaks down the food into . . .

Mr. Poole: [Interrupting] Well, actually the food started breaking down in your mouth. What does your stomach do? Anyone? [Pointing] Rachel?

Rachel: Uh . . . that's where the food . . . uh . . . goes into your body.

Mr. Poole: Not really. Michael, do you know?

Michael: The stomach adds acids and chemicals to break down the cracker.

Mr. Poole: Right. The stomach adds digestive acids to break down the cracker into energy that your body uses.

As you can see, Mr. Poole's questioning technique is quite unstructured. Most of his questions are at a low-level recall or knowledge level. He also asks a number of "Guess what I'm thinking of" questions. The way Mr. Poole poses the questions creates an atmosphere in which students try to anticipate what answer he wants. When Mr. Poole doesn't hear the answer he is looking for, another student is called on until the "correct" answer is given. Although the teacher posed many questions to the class, this does not represent an inquiry lesson. In addition, Mr. Poole did not provide sufficient time for students to accurately answer several of his questions. He often interrupted the student in the middle of an answer. Unfortunately, today's teachers are pressed to pack a great deal of learning into the school year. Could this be why so many teachers are pressed to use a rapid-fire approach when asking questions?

WAIT-TIME

Mary Budd Rowe is a noted educator for her research on *wait-time:* the length of time a teacher waits between the end of the student's response (to a teacher's question) and the beginning of the teacher's next question. Rowe (1974, 1987, 1996) reported that teachers wait about 1 second following a student's answer before either repeating the answer, asking the student another question, or calling on another student. Her research indicated that when teachers practice short wait-time techniques (1 second), students tend to give simple and short answers at a low-recall level. However, Rowe suggested that by pausing to wait 3 to 5 seconds after a student's response, desirable behaviors often result. Rowe, and also Tobin and Capie (1981), reported that as the use of wait-time increases, so do the following:

- The number of student responses
- The number of unsolicited but appropriate responses
- The use of higher levels of logical thinking
- The incidence of speculative thinking
- The number of questions students ask
- Students supporting their answers with evidence, logic, and details
- Student-to-student communication and exchanges
- The number of positive responses
- The students' confidence in their ability to construct explanations

And by waiting an uninterrupted pause of 5 seconds or longer, Rowe reported that the length of the student responses increased by 3 to 7 times!

Rowe (1974, 1987, 1996) also reported that teachers who use longer wait-time techniques have additional time to think about students' answers and focus more on students' responses. This allows teachers to concentrate more on understanding the reasoning and points of view of their students.

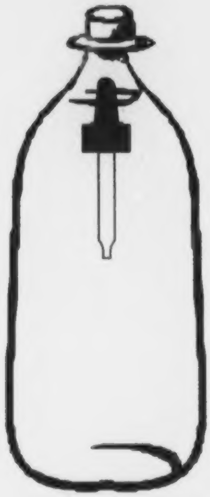
In one study, Rowe asked teachers to identify five of their best and five of their slowest students. When observing the wait-time techniques of those teachers, Rowe found that teachers waited significantly less time for slower students than they did for brighter students. After reviewing the data, teachers surprisingly admitted they did not expect the slower student to provide the correct answer, so they went on to another student. In the lesson with Mr. Poole, we can see that he did not use effective wait-time techniques, thus many of the students' responses were brief.

ANSWERING QUESTIONS AND QUESTIONING ANSWERS

Teachers probably ask hundreds of thousands of questions over the course of their careers. Knowing how to ask questions and when it is appropriate to give an answer to a question are important aspects of teaching. To illustrate this point, let's consider a hypothetical seventh-grade physical science class. (Teacher and student names are fictitious.)

Mr. Rivers has 15 stations set up around the room. Each station has an activity that demonstrates one or more science process skills. The purpose of the lesson is to have students engage in activities to gain an understanding of those skills. By doing the activity

Figure 9.2. Cartesian Diver



and then determining which science skills were being emphasized, the students are constructing an understanding of the skills.

The students work in groups of two, rotating from station to station. One station has a Cartesian diver (see Figure 9.2). A Cartesian diver is made of an eyedropper partially filled with water so that the tip of the eyedropper just floats at the top of a 2-liter, clear plastic bottle also filled with water (see Resource E on how to make one).

At this station, the students are instructed to gently squeeze the sides of the bottle and observe what happens to the "diver." Next, they must go on to devise an illustration or a model to explain how the Cartesian diver works.

In one group, Tim and Bernie indicated that they didn't have the faintest idea what was going on inside the bottle. The answer is relatively simple, and Mr. Rivers assumed that both students had enough understanding of volume and pressure to solve the "mystery." So, he decided to pose several prompting questions to guide them to an understanding.

Mr. Rivers: When you squeeze the bottle, what happens to the diver?

Tim: It goes down.

Mr. Rivers: Good. Now, as you squeeze the bottle, what happens to the volume inside the bottle?

Bernie: What do you mean?

Mr. Rivers: Well, as you squeeze the bottle does the volume inside the bottle increase, decrease, or remain the same?

Bernie: I'm not sure.

Mr. Rivers: Okay, let's try this. [Reaching for a can of soda] If I were to crush the can, what would happen to the soda inside the can?

Bernie: It would come out.

Mr. Rivers: Very good. Why does the soda come out?

Bernie: Because you squeezed the can and there's less room inside the can for the soda . . .

Mr. Rivers: [Silence]

Tim: So . . . since there is less room in the can . . . the soda has nowhere for the soda to go but to spill out . . . Right?

Mr. Rivers: Right! Now use that to answer what happens to the volume when you squeeze the Cartesian diver?

Tim: The volume decreases?

Mr. Rivers: Are you sure?

Tim: Yeah, the volume decreases!

Mr. Rivers: Okay, now if the volume of the bottle decreases, what happens to the pressure in the bottle when you squeeze it?

Bernie: It probably increases.

Mr. Rivers: It does increase, you're right. Now, because the volume inside the bottle decreases, what happens to the water inside the bottle?

Bernie: It goes up the little diver?

Mr. Rivers: How do you know?

Bernie: I saw it go up.

Mr. Rivers: You mean, you observed the water going up.

Bernie: Yeah.

Mr. Rivers: What did you observe that told you the water was going up the diver?

Tim: I saw the water go up . . .

Mr. Rivers: [Silence]

Tim: The little level thing went up higher in the diver . . . so that probably means the water is rising up into the diver.

Mr. Rivers: Good observation! Now, as the water rises up into the diver, what happens to the diver?

Tim: It goes down because it has more water in it and it weighs more . . . so that makes it sink to the bottom of the bottle.

Mr. Rivers: [Silence]

Tim And so when I stopped squeezing the bottle . . . the pressure went back to normal . . . and the volume of the bottle increased . . . forcing the water back out of the diver . . . and the diver went back up!

Mr. Rivers: Good job! So what did you need me for? You knew the answer.

Bernie: I didn't think I did.

This brief lesson shows us the effective use of wait-time and the power of posing questions to elicit the student's prior knowledge. What goes through the mind of a teacher like Mr. Rivers the moment a student asks him a question? In that split second just after the question is asked, at the start of the student's answer, he might ask himself, "Does this student have any idea in his head how to answer this question?" If the answer to this question is "no," he probably feels it doesn't make any sense to try to coax an answer out of the student. Instead, he provides a direct and appropriate answer. Posing a question to try to "pry" an answer out of someone's head when the information isn't there makes a frustrating situation for both the teacher and the student. If he thinks, however, that the student has some prior knowledge or experience that can be used to answer the question, then prompting and probing questions would be more appropriate than providing an answer.

TYPES OF QUESTIONS

During the Cartesian diver discussion, the questions the teacher asks are important in directing and focusing the thinking processes of the students. His questions also direct the students toward an intended goal: understanding how the diver works. In inquiry discussions, the teacher's questions can be classified into four types:

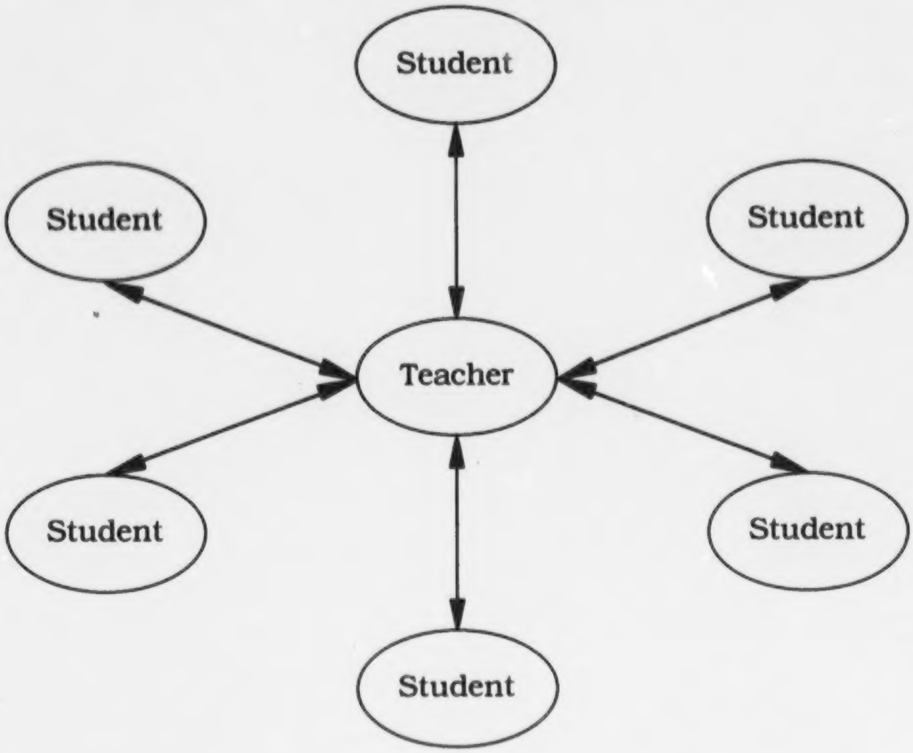
1. *Clarifying questions* require students to make their thoughts and understanding more explicit. We ask these when students fail to provide reasonable explanations. Clarifying questions ask the student to restate his or her understanding, elaborate further, or articulate a particular position on a topic. Teachers often pose clarifying questions by asking "What do you mean by that?", "Can you be more specific about that?", or "What's the significance of that?"

2. *Focusing questions* require students to narrow their answers and provide more specific responses. We ask this kind of question when students provide vague or generalized answers. Teachers often pose focusing questions by asking "Can you give me an example of that?"

3. *Probing questions* require a student to justify a response, support a point of view, or analyze a situation to make further generalizations, formulate outcomes, or state a cause-and-effect description. They are aimed at correcting, improving, or expanding a student's original response to a question (Moore, 1994). Teachers ask probing questions when students' answers are flimsy or partially explained or when they feel students know more than they are answering. Probing questions encourage students to clarify answers by providing more evidence or giving supporting details. They also cause students to think and respond at higher cognitive levels. Teachers often pose probing questions by asking, for example, "What if you tried adding more soap solution?", "What do you think will happen if you used a larger marble?", "What do you mean by that?", "What are you thinking about when you say that?", or "What do you think you should do next?"

4. *Prompting questions* require students to provide answers that are guided by questions asked by the teacher. We ask prompting questions when we want a student to come to a particular conclusion. They often contain clues or hints to guide the student to answering correctly. Sometimes, a teacher will use a prompting question as a follow-up question when a student cannot answer an original query correctly. Rather than say that he or she did not answer correctly, a teacher can follow up with a prompting question that is simpler and more direct. This kind of question is reworded from the original question with additional hints and suggestions (Moore, 1994). When a student's response seems to be scattered, the teacher can pose a prompting question that tends to lead to an obvious answer. Some examples of prompting questions are "Don't you think you should try it again?", "Have you thought about trying to increase the angle of the ramp?", "Have you tried using more paper clips?", and "What can you do to the Bugs-o-Copter to make it fall faster?"

Figure 9.3. Teacher-to-Student Interaction in Questioning



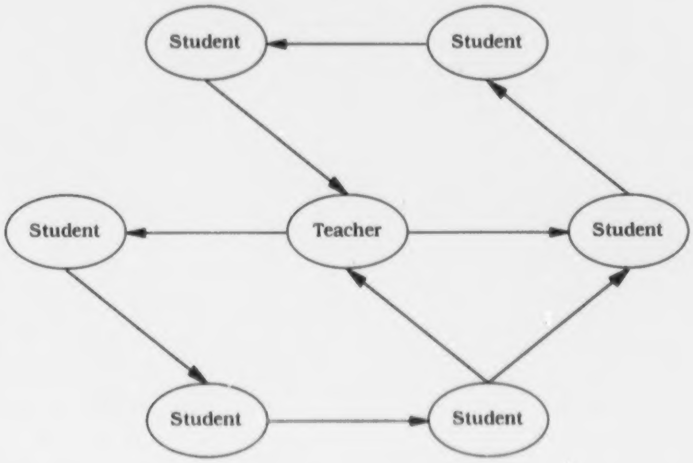
INTERACTION OF QUESTIONING

Looking back on Mr. Poole's lesson on nutrition, a distinct communication pattern emerges. The interaction between the teacher and the student starts with the teacher asking a question and a student responding with an answer. The teacher goes on to ask another student a question, expecting a particular answer. The pattern shows the direction of communication from teacher to student and back to the teacher again (see Figure 9.3). This type of questioning limits the interaction to just two participants: the teacher and the student being asked the question.

Redirectioning, on the other hand, is a technique used by teachers to involve many students in a discussion. During redirectioning, the teacher will call on one student and ask another student to build on the comments from the first student. Redirection encourages students to listen and become aware of other students' comments. Students must not only listen to their peers, they must also analyze and be able to react to previous comments made during the discussion. During redirectioning, a typical questioning pattern would look something like the one in Figure 9.4.

A teacher using redirectioning calls on one student and asks another student a follow-up question. The discussion may sound something like the following (teacher and student names are fictitious):

Figure 9.4. Redirecting Interaction in Questioning



Mr. Lopez: *In your leaf experiment, why did you give the plants all the same amount of water? Jason?*

Jason: *Because if you changed the amount of water, some plants would get a lot of water and some just a little . . . and that might affect the results of your experiment.*

Mr. Lopez: *Margaret, is Jason right?*

Margaret: *Yeah, you have to give all your plants the same amount of water to make it a fair experiment.*

Mr. Lopez: *[Silence]*

Ann: *I think that if you changed the amount of water you give each of the plants, it would change the outcome of the experiment, and you want only one variable to affect the outcome.*

Margaret: *That makes the amount of water one of the controlled variables in the experiment.*

Michael: *But what about amount of sunlight the plant receives, shouldn't that be the same too?*

Margaret: *Yes. That makes the amount of sunlight another one of the controlled variables in the experiment.*

In another example of redirectioning, the teacher can say, "I'm going to ask Michelle a question, then I'm going to ask a boy a follow-up question." By prefacing the question to Michelle with that statement, the boys are asking themselves "Am I going to be called on next?" This technique helps keep all the boys attentive and listening to Michelle's answer.

Sometimes, students know the answers, but they lack experience in communication. We might hear a student say "I know the answer, I just can't explain it." Sometimes, that can mean "I don't know what you are talking about" or "I need help." In these situations, consider how to pose prompting questions to help students think about their own thinking.

To include all students in questioning, teachers should distribute questions equally and equitably throughout the class. As an exercise, you could go into a teacher's room and observe which children are called on to answer a question. Make a diagram of the classroom's seating arrangement and label each desk with the gender of the student sitting at it. Throughout the lesson, place a tally mark in the box representing the desk for each time the teacher poses a question to that student. Also, write the name of the student in the box when, and only when, the teacher calls on the student by name. This will show you three things: (a) the frequency with which the teacher calls on boys versus girls, (b) the degree to which the teacher personalizes the class by calling on students by name, and (c) which areas of the room get the most attention. If there are 28 students in the class, and only 5 have names filled in their boxes, chances are, the teachers does not personalize the questions by calling on the students by name.

In addition, draw a line to indicate the movement of the teacher throughout the lesson. Do you observe the teacher moving about the room or staying in one spot? Does the teacher call on students sitting directly in front of him or her? Because teachers often call on students in their immediate vicinity, I often suggest that they move about the room and ask questions from the back of the room to students in the front. As your observation techniques get better, you may want to tally how the teacher responds following an answer. Does the teacher repeat the answer, provide positive reinforcement, say "Okay," ask a follow-up question, or say nothing and go on to another question?

There are always a few students who are shy or afraid of giving wrong answers. Start questions to nonvolunteering students by letting them know you are going to ask the question. To avoid any undo embarrassment, get their attention first by calling on them by name. Pose questions that are fairly straightforward and easy to answer. Following an answer, wait a few seconds, and if there is no further response, provide positive reinforcement by saying "Yes, that's right! Good answer. Thank you."

Chapters 7 through 9 provided instructional strategies that teachers can use to enhance inquiry-based classrooms. In the next chapter, we hear from two teachers describing how they have come to construct an understanding of inquiry and how they use inquiry in their classrooms.

10

Inquiry-Based Teachers Describe the Process

Teachers who use an inquiry-based approach in science can offer guidance to those contemplating using inquiry in their own science classrooms. What follows are two separate conversations I had with two different teachers. Both of them are familiar with the challenges and rewards of teaching through inquiry.

DANIELLE DZINBAL

Mrs. Danielle Dzinbal is a fifth-grade teacher in Rochester, New York. Although Danielle is a veteran teacher of 25 years, she describes herself as a relative newcomer to inquiry. She says she's "just getting her feet wet" after 2 years of using an inquiry approach. Here are her responses to my questions on that subject.

What does inquiry mean to you?

Danielle: That question is still hard for me to answer. I think inquiry means to be able to look at something and reflect on that particular phenomenon. During inquiry, one asks a series of questions: Have I ever seen this before? Do I know anything about it? Can I relate to it in any way? What does it conjure up in my mind? I'm still trying to digest the whole idea of inquiry.

How would you describe your classroom?

Danielle: My classroom varies from day to day. Some days, students bring in things from their home or neighborhood, like a bird's nest to observe with a *hand lens. They like to share their ideas. Kids need to feel free to discover, and the classroom is a great place to fulfill that need. Sometimes, the classroom can be described as teacher centered, and at other times, very student centered. Sometimes, the lessons are very structured, and other lessons are very unstructured. I want my classroom to be a place where children are not afraid to express their ideas, where feelings are openly discussed, and where there is no embarrassment for giving wrong answers or saying "I don't understand." My room is constantly changing and the kids have a big say in the arrangement of the room, how the seats and desks are arranged, and so on.*

If a visitor came into your classroom, what would he or she see students doing?

Danielle: We have a lot of visitors coming into the classroom, including parents, student teachers, and other teachers. They would probably see children working in groups on a variety of topics. Some students would be helping and monitoring other students. Others may be working on evaluative kinds of projects. Overall, I hope they would see students showing that respect, and courtesy takes high priority, not only in our classroom but in the world too!

What would he or she see you doing?

Danielle: I think I'm pretty typical of many teachers that encourage student engagement. I would probably be talking and helping students and modeling the kind of behavior I expect from them. I believe that's an important value to hold in teaching. I might be reading books to a group or tutoring those that need a little extra help on their school work. I also think it's important to show my students that I have a very human side. That means I often share my thoughts and feelings as a person, aside from being a teacher. I also emphasize communication skills needed to read and write effectively.

If inquiry-based teaching takes more time, how do you balance your teaching style with meeting the district's standards, curriculum, and testing requirements?

Danielle: The balancing act of inquiry is still very difficult for me. Most of all, I really have thought about all the things I'm doing right versus all the things I think I'm not. Having to select what topics I have to leave out is always very difficult for me. But I do think when students feel they have some control in the ways they learn and are evaluated, they do much better. Is inquiry teaching easy? No. It takes at least twice as much time, plus you have to be twice as prepared. It takes a lot more time researching and making the materials available with connections to literature and other subject areas. But in the end, it's all worth it because I see what the kids get out of inquiry-based investigations and how they grow in their ability to think for themselves.

Inquiry teaching is often characterized as valuing the students' point of view and encouraging them to engage in raising and answering their own questions. How do you deal with the questions your students ask?

Danielle: Questions are something that are always encouraged in my classroom. I don't feel guilty when I don't know the answer to something or even when I make a mistake. It enables my students to see me as a very human person, *one who makes mistakes and has questions of her own. Questions from students are dealt with either immediately or as something we all can investigate and share. Before adopting an inquiry approach, I would sometimes sidestep student questions because I didn't know the answers. As a teacher, I felt I should know all the answers to all questions. So I'd say, "We'll talk about that later," knowing full well we wouldn't. It was just avoidance. Now, I'm not afraid to say, "I don't know, but let's find out how we can get an answer." Years ago, I would ask questions that required simple answers. Now, I encourage students to question where they have to use their "thinking caps" to analyze or evaluate or provide some supportive evidence for their answers. My questioning skills have certainly developed over the years.*

What special skills do students experience when learning through inquiry?

Danielle: Through inquiry, I feel students are better able to ask questions and pursue their own answers. It encourages self-responsibility and lifelong learning. It also enables them to design a reliable investigation, become strong in their convictions, and to value other people's points of view and ideas. They seem to be less afraid to ask questions in front of their peers and hopefully, they feel they can make a contribution, whether it's big or small, to the group they are working with. And I see kids taking on leadership roles in group settings and feeling good about themselves. That's what school should be all about.

How are your planning or presentation skills different from a traditional lesson when using inquiry? Do you see any difficulties in teaching through inquiry?

Danielle: It's always a risk to move from teaching 20 years in a comfort zone into a new way of teaching. Now, I'm wading into water that I'm not quite sure about. So, that conjures a whole new set of fears for me. Inquiry requires a lot more time than direct instruction or traditional teaching methods. Not everyone is willing to put that much energy and effort into teaching. It takes a lot of conviction to redirect your teaching efforts well into your teaching career. It takes a long time to get where you want it to be. It goes better when you can share ideas and goals with another colleague or group. It requires commitment on a daily basis. It needs to be interwoven with the reality of teaching the basic skills one needs to learn. I believe traditional lessons are still a necessity. I still haven't given up completely on direct instruction. Juggling between the two is sometimes very tedious. A school's make up, philosophy, and teacher schedule impact greatly on this type of teaching. It takes the ability to say "I know what I have to teach. I'm just going about it in a different way." My level of inquiry instruction varies from year to year, depending on the skills of the students. Some years, I have much more of a challenge in getting my kids to do some of the questioning and researching I want them to learn. It takes a lot of my energy to keep them directed and on track with the core curriculum.

To do inquiry well, you need a level of discipline. Because inquiry requires kids to be free to get up and about at different points of the lesson, they need to have a degree of self-discipline, independence, and responsibility to carry out many of their investigations. Some years, kids come into my room in September lacking the skills they need to be independent, account-

able learners. And that's reality. So, to make inquiry effective at each grade level, the philosophy has to be adopted school wide so students receive that kind of instruction throughout their entire elementary years. It takes a great deal of effort to implement inquiry strategies when kids have come from a traditional, teacher-centered classroom the previous year. And what happens when they leave you and go on to a teacher with a traditional setting? Boy, that's a tough one.

At what stage or level do you see yourself, presently, in developing the instructional capacity to become an inquiry-based teacher?

Danielle: On a scale from 1 to 10, I believe I'm at a level 2. I'm at this level because I've told myself I need to go slowly. I also realize my limitations given my school schedules, curriculum requirements, paper work, and personal life. I still, through all of this, feel I've made headway from the start of my career. I'm trying to get away from always being in front of the room and directing my teaching at students and expecting certain answers in return, to giving students the opportunity to investigate a question to see what they can come up with. Part of the problem is in getting kids to ask questions. They aren't used to asking questions. Some of my students are still reluctant to ask questions.

What resources or staff development do you think you need to further your skills as an inquiry teacher?

Danielle: I continue to take courses, observe other teachers, and read extensively on the subject. I feel ongoing seminars are greatly needed in the district on inquiry teaching. A seminar here and there won't do it. Yearly observations of others involved in this type of teaching are a necessity. Everyone needs to see how inquiry is done in the classroom, so visiting teachers who are good role models is essential. Then, in the best of worlds, you need time to sit down with these teachers and discuss what they did and why. I think the discussion and discourse aspect is an essential part of interacting with the "experts" out there. Having a support group to share materials and ideas would be very helpful.

What advice would you give to other teachers just starting out in establishing an inquiry-based classroom?

Danielle: Don't panic and go slowly. Try and find a colleague or another teacher in your school to partner with. Form discussion groups to connect with other teachers who value what you do. Be realistic according to the type of school you are at and the faculty you work with. Attend workshops. Don't throw your traditional teaching out the window. Believe in yourself. Realize that each new class will bring new gains and setbacks. Teach yourself how to inquire and be a good role model to your own students.

LUCIA FALSETTI GUARINO, PHD

Lucia Falsetti Guarino is an assistant professor at St. John Fisher College in Rochester, New York. She is a veteran teacher with extensive experience in curriculum, instruction, assessment, and staff development. Prior to her work at the college level, Dr. Guarino taught seventh- and eighth-grade science. Like many inquiry teachers, she started out teaching through hands-on activities and then began to read and research about inquiry and constructivist methodologies. She says that reading research and philosophy education articles about the Learning Cycle has helped her articulate an understanding of her teaching style and become a better teacher.

What does inquiry mean to you?

Lucia: I feel confident saying inquiry is something we never know the total meaning of because the more I read about it, the more I realize how incredibly broad a topic inquiry is. So many people have definitions that are different from one another. Some have broad philosophical definitions and some have very narrow definitions. Yet each one is valid. I used to think I absolutely had to know the answer to that question, but now I realize we don't always have to have just one answer.

When doing inquiry, I think about students raising engaging questions instead of doing cookbook labs. As a science teacher, I had students engaged with problems that caused them to think. I was always interested in inquiry, although I didn't know that what I was doing actually was inquiry. Later, I found out through reading a research monograph that a lot of what I was doing was described as the Learning Cycle. I realized why I would never introduce vocabulary until we had completed a concrete experience to bring out the concept. Reading about the Learning Cycle helped me to put labels on what I viewed good science teaching was all about.

I am still struggling with my definition of inquiry, although I focus my understanding of it on the desire to take a student's thinking to a higher level. Students in my graduate level courses always want a definition of inquiry. They don't seem to be comfortable with doing the hard work of constructing an understanding for themselves.

How has your definition of inquiry evolved over the years?

Lucia: I used to view inquiry in a limited way—asking questions and providing help to students. Now, I see inquiry as a process in which we are all searching for understanding. In doing that, I am making my students feel a slight level of discomfort while constantly asking questions and having their minds constantly processing information. I find this results in a heightened level of curiosity on the part of the students. My understanding of inquiry today is different then it was a year ago and probably different than it was yesterday. It keeps changing. As I said, I'm always struggling with my understanding of inquiry to fit the pieces together. Before, I used to have trouble with that. Teachers are expected to have the answers, but now I realize that struggling with a phenomenon is a natural way of constructing knowledge. That's how we learn. Today, I am comfortable with the fact that I can have a doctoral degree and still be searching for answers and to make sense of my teaching.

How would you describe an inquiry-based classroom?

Lucia: To me, in an inquiry classroom you would not notice the teacher standing out among the students. You might see the teacher sitting alongside a student desk talking with a group of students. You would see the teacher working with groups where the learning is focused on what the students are doing, not what the teacher is doing or saying. The teacher is working with *the groups, trying to determine how she is going to get them to work at the next level.*

Some traditional classrooms I observe are so bland. In an inquiry classroom you would see life going on! You see curiosity in the faces of the students! There is noise and "stuff" going on. On the walls you would see KWL charts [What do you know? What do you wonder? What did you learn?], inquiry questions, student work, and concept maps, both in progress and as finished work. Keeping student work visible is an important aspect of an inquiry classroom. That helps us to keep looking back at our questions and explorations. When our questions are placed on an overhead, we tend to put them out of sight.

You also would see students feeling comfortable talking with the teacher. There is a definite rapport between the teacher and the students, with more emphasis on personal relationships. Although it's hard to describe, you also see a comfort level and sense of belonging between the teacher and her students. Trust is another aspect you see among all the members of the classroom. Lastly, in an inquiry-based classroom, there is always a sense of intellectual tension because there are always unanswered questions to ponder.

If inquiry-based teaching takes more time, how do you help teachers balance their teaching with meeting the district's standards, curriculum, and testing requirements?

Lucia: When I was a classroom teacher, I used to streamline lots of units I taught. If you do inquiry, you need all the time available. I remember once that it was nearly the end of the year and I had another whole unit to teach. It was "reproduction." So, out came a packet of dittos because the topic was going to be on the final exam. The students had to be prepared one way or another. It's difficult to find the time to do full-scale inquiries when you don't have control over the final exam. There's no easy answer to this issue.

You have to make some tough decisions about what to teach in-depth and what to leave out. In inquiry-based classrooms, you need an enormous amount of time to talk with your students and time for them to explore their interests. It's always a difficult choice. You can either have the students learn something really well and enjoy it or cover a lot of topics by just skimming the surface. It all comes down to what you value in your classroom. To me, developing higher-level thinking skills and empowering students to think on their own is just as important as knowing the asexual reproduction of an amoeba.

Inquiry teaching is often characterized by valuing the students' points of view and encouraging them to engage in raising and answering their own questions. How do you empower teachers that you work with to respond to the questions their students ask?

Lucia: I think one of the hardest things for teachers to understand how to do is acknowledging where student questions are coming from—their heads and their hearts. You can't "blow off" students' questions, because the questions become very personal to the students. You must respect students' points of view. Even though the questions students raise may be far-fetched, they still *need to be valued and addressed accordingly. You are always balancing your agenda versus the students' agendas. And sometimes, we have to yield to a student's agenda or question. Certainly students take us off track on occasions, but valuing their questions, as long as they are authentic questions, means taking time to discuss and work them out. I often try to have teachers see a question through the eyes of a student. When you learn that, you learn to value their questions as an integral part of your lessons. Your science lessons can't become detached from student questions.*

What special skills do students experience when learning through inquiry?

Lucia: The most important skill they learn is how to pose questions. Recently, I had a graduate-level student who works in industry. She said industry can't find people to hire who can pose questions. They also can't find people who can develop a procedure while keeping the "end" in mind. When a student asks a question, I ask him, "Why do you think this is going to happen?" Of course, his answer is usually "I don't know." So, I then have him reflect and do some further thinking about his answers. Another skill is learning the importance of measuring and data collection and to use the appropriate instruments. Knowing what to use in an experiment is a skill in itself. Through inquiry, students also learn how to communicate, think scientifically, and do what I call "action research." Action research is different from just looking up an answer in a book. It's designing a procedure to a question, struggling with mathematics and organizing data tables, and making sense of their results. Too many teachers think that inquiry is just either posing questions to students or having them look up answers to questions in science resources. In order for kids to gain the scientific literacy associated with inquiry, their research has to center around action.

What is the biggest "hurdle" teachers need to get over when starting to use inquiry strategies?

Lucia: I see the biggest hurdle as breaking out of the mold that the teacher has to have all the answers. Too many teachers fear being challenged by students and having to always give answers to their questions. Sometimes I have to tell students "I don't know, but let's see how we can find the answer together." I also have many students that challenge my thinking and the positions I take on certain topics. At first, I was uncomfortable with anyone challenging my authority, but I have adjusted to that, and as a result, I feel we both benefit. There is a Russian word for this, "obucher." It means to be both a teacher and a learner. I don't believe we have a word similar to this in English.

Another hurdle is being afraid of losing control. Teachers feel a lot of pressure to maintain a quiet and orderly classroom. In working with teachers developing their inquiry strategies, we sometimes see a group not functioning well. It becomes frustrating not knowing what's going wrong with a group, and you are stymied on what to do or how to set them back on the right path. I have teachers tell me they felt that they are the ones expected to come in and fix everything. It's what students expect of teachers.

For other teachers, the organization of an inquiry is a big hurdle. Inquiry classes are going to be messy. Kids are going to be up and moving along at *different rates. That places students at different points of the exploration. Some need more attention than others, and some students need different kinds of help or scaffolding. It's like the kind of interaction that goes on between a parent and child as the child is learning to speak. It's natural, but we don't see it as part of the curriculum. It's not as neat and as orderly as you would like it. It's a situation different from what most teachers are used to. A preconception that some have about inquiry is that you can only do inquiry with higher-achieving or gifted students. When in reality, inquiry is for all students regardless of their abilities or disabilities. I see inquiry as a way to enhance one's thinking skills and it should not be afforded to a certain population of the students. Inquiry is for everyone!*

According to* National Science Education Standards*, "current reform in science education requires a substantive change in how science is taught." In working with teachers, how do you help teachers to teach science?

Lucia: First of all, I come into the classroom and observe what's going on. It's like the observation stage of inquiry. I then suggest a specific strategy which we work together on that is designed to increase the students' learning of science concepts and processes. In some cases, I work with teachers to rewrite the lessons they are using and are familiar with. We work together to make these lessons more open-ended so students can explore a concept without being told each step to do along the way. I find it's always easier to take what we already know and transform it into an inquiry lesson. I also believe it's important for me to model the kinds of behaviors that we are looking to improve upon. By doing that, it establishes credibility and shows rather than just says what a teacher should do differently. The modeling process also helps to establish a level of trust between the teacher and myself. That's important if we are going to continue to work together. Most teachers come to me voluntarily. I try to provide them with a bank of "tools" to enable them to use inquiry and the Learning Cycle. In working with teachers, I find I have to question and challenge their beliefs. We also discuss that inquiry is not a panacea. Inquiry, like any other teaching strategy, needs to be selected at the appropriate time. We all have to teach didactic lessons sometimes, but when we get into inquiry situations, we discover that "I thought I knew this but now I don't know beans about this."

What advice would you give to other teachers just starting out in establishing an inquiry-based classroom?

Lucia: Start simple with something you can handle. I had a social studies teacher I was working with who had her students raise a number of questions around a concept they were studying. We divided all the questions that the students raised into four general questions and organized tasks for each of the questions. Students selected the task they wanted. In researching the answers, students went out into the community and collected data. The lesson became a nice balance between providing structure and letting students' questions guide the direction of the lesson. In another situation, the students came up with one question and each group then developed its own procedure to solve the problem. I find there aren't any rules for doing inquiry. The only rules are the ones that work for you. That's it.

SUMMARY

Although Danielle and Lucia differ substantially in their experiences with inquiry, one similarity exists between them: They both have spent considerable time reading books on inquiry and discussing their ideas with other inquiry-based teachers. To continue your reading, in Resource A you will find a collection of print, videotape, and electronic resources of interest on inquiry.

Resource A

Inquiry Resources for Teachers

If you make a commitment to become an inquiry-based teacher, you are making a determination to continue your intellectual and professional development throughout your entire teaching career. Professional growth often comes in the form of reading, attending workshops, summer institutes, and seminars, taking graduate-level courses, or collaborating and exchanging ideas through support groups and online forums.

For some, this book may be the beginning of an exploration into inquiry. For others, it may be one of many resources that help you construct your understanding of inquiry. Whatever the case, your reading and discussion into inquiry-based teaching should be ongoing.

The purpose of this section is to familiarize science teachers with some of the many resources that are available on inquiry teaching. This annotated bibliography serves to reinforce the idea that further reading is an essential component in becoming an inquiry-based teacher.

Books and Magazines

Inquiry and the National Science Education Standards:
A Guide for Teaching and Learning (2000)
National Research Council
National Academy Press
ISBN# 0-309-06476-7
A new and comprehensive guide for implementing inquiry in the science classroom. Excellent reading to accompany National Science Education Standards (NSES). *Contains useful strategies for teachers and numerous vignettes as examples. Highly recommended.*

Inquiring Into Inquiry Learning and Teaching in Science (2000)
Edited by Jim Minstrell and Emily Van Zee
American Association for the Advancement of Science
ISBN# 0-87168-641-4
An excellent collection of articles that will apply to the novice and the experienced inquiry teacher. Highly recommended.

Inquiry Works! Real Teachers, Real Stories (2000)
Concord Consortium
NETWORK, Inc.
ISBN# 0-615-11195-5
Frontline stories and explorations about the challenges and excitement of bringing inquiry teaching to classrooms across the country. Recommended.

A Theory of Instruction: Using the Learning Cycle to Teach Science Concepts and Thinking Skills (NARST Monograph No. 1, 1989)

Anton Lawson, Michael Abraham, and John Renner
National Association for Research in Science Teaching

Provides a theoretical and historical background on the Learning Cycle. Contains empirical studies and implications for the classroom. Recommended.

Inquiry: Thoughts, Views, and Strategies for the K-5 Classroom (Foundations Monograph Series, Vol. 2, 1999)
National Science Foundation
Available online at: www.nsf.gov/pubs/2000/nsf99148/start.htm or from Triangle Coalition for Science and Technology Education, 1201 New York Avenue, NW, Suite 700, Washington, DC, 20005 (phone 800-582-0115)

A free beginner's guide to science inquiry. Provides introductory information on inquiry. Highly recommended.

The Challenge and Promise of K-8 Science Education Reform (Foundations Monograph Series, Vol. 1, 1997)
National Science Foundation

A free beginner's guide to science education reform and the importance of inquiry. Provides introductory reading on leadership, curriculum, instruction, assessment, and professional development. Recommended.

ENC Focus: Inquiry and Problem Solving (Vol. 6, No. 2, 1999)
Eisenhower National Clearinghouse (ENC) for Mathematics and Science Education
Available online at: www.enc.org. For a free subscription to ENC Focus, call 800-621-5785 or go to their Web site at: www.enc.org/order/

Features articles on teachers using inquiry and problem solving in their classrooms. Recommended.

Science as Inquiry (2000)
Jack Hassard
Good Year Books
ISBN # 0-673-57731-7

An excellent resource for upper elementary and middle school teachers looking for a complete guide to direct active learning and project-based activities. Contains Web sites and assessments strategies to promote inquiry-based learning. Recommended.

Primary Science: Taking the Plunge (1985)
Edited by Wynne Harlen
Heinemann
ISBN# 0-435-57350-0

One of the best books on how to help children raise questions, observe, record their work, and plan scientific investigations. The authors' considerable experience in constructivist principles and inquiry-based instruction makes this book practical as well as research-based. The chapters on "children's questions" and "planning investigations" are especially helpful. This is a book that you will come back to several times. Highly recommended.

In Search of Understanding: The Case for Constructivist Classrooms (1993)
Jacqueline Grennon Brooks and Martin Brooks
Association for Supervision and Curriculum Development
ISBN# 0-87120-211-5

This book is an excellent starting point for reading about constructivism and its application to teaching strategies. Although the book applies to all content areas, science teachers *will find this book helpful in gaining a baseline understanding of constructivism. The book is easy to read and is filled with practical suggestions for classroom practice. Combined with a set of accompanying videos by Association for Supervision and Curriculum Development (ASCD) (see "Multimedia"), it makes an excellent resource for professional development sessions. Highly recommended.*

Science for All Children: Lessons for Constructing Understanding (1999)
Ralph Martin, Colleen Sexton, and Jack Gerlovich
Allyn & Bacon
ISBN# 0-205-29373-5

If you are looking for sample lessons based on the Learning Cycle, you will find this book useful. Part 1 presents the 4-E method (Exploration, Explanation, Expansion, and Evaluation) for lesson design. Part 2 offers safety concerns for a hands-on science classroom. Part 3 presents more than 100 lessons (many may be familiar) in life, physical, earth, and space sciences for Grades K through 8. Lessons are correlated to national science standards. Recommended.

The Young Child as Scientist: A Constructivist Approach to Early Childhood Science Education (1991)
Christine Chaille and Lory Britain
HarperCollins
ISBN# 0-673-38857-3

In a book devoted solely to early childhood, the authors present a background for viewing the child as a theory builder to rethink the way children learn science and how this approach is different from traditional models. This book looks at the constructivist classroom and how its physical arrangement enhances social interaction and problem solving. The role of the teacher in such a classroom is also examined. The book also provides lessons in physical, earth, and life sciences, showing how to bring a constructivist perspective to the classroom. Highly recommended for K-2 teachers.

What Children Bring to Light: A Constructivist Perspective on Learning in Science (1994)
Bonnie Shapiro
Teachers College Press
ISBN# 0-8077-3375-X

Becoming an inquiry and constructivist teacher starts with listening to what children say. This book helps teachers understand the historical development of constructivism and become better listeners by providing several case studies of children explaining and exploring their perceptions of light, reflection, absorption, and vision. The case studies also provide a look into multiple intelligences and how a child's perception affects his or her understanding of physical science concepts. Highly recommended.

Invitations to Science Inquiry, Second Edition (1987)
Tik Liem
Science Inquiry Enterprises
ISBN# 1-878106-21-X

If you like to do dynamic demonstrations and discrepant events as ways to stimulate inquiry, this book contains over 400 quick and easy means to get your students "fired up" with science. All the discrepant events include lists of materials necessary to complete the demonstrations, the procedures to follow, questions to pose after the demonstrations to stimulate inquiry, and an explanation of the scientific concepts involved. Most demonstrations can be completed with common science materials. Demonstrations are provided for *life, earth, and physical sciences. A must for those who like to be a Mr. or Ms. Wizard. Highly recommended for teacher of Grades 3 through 8.*

Learning and Assessing Science Process Skills, Third Edition (1995)
Richard Rezba, Constance Sprague, Ronald Fiel, H. James Funk, James Okey, and Harold Jaus
Kendall Hunt
ISBN# 0-8403-8430-0

Having an understanding of science process skills is a prerequisite for teaching inquiry. This book takes readers through a step-by-step approach to increasing their understanding of basic skills, such as observing, communicating, classifying, measuring, inferring, and predicting. Part 2 includes integrated skills needed to conduct a scientific investigation. The chapters follow a self-paced, individualized process that provides hands-on activities to practice each skill. The new edition also provides assessment strategies for each science skill. Highly recommended for individual teachers and for use in professional development workshops on science process skills.

Collaborative Inquiry in Science, Math, and Technology (1998)
Dennis Adams and Mary Hamm
Heinemann
ISBN# 0-435-07143-2

This book provides a general overview for cooperative learning and critical and creative thinking skills, as well as inquiry opportunities in science, mathematics, and technology. The science sections outline specific science process skills and offer several student activities that invite inquiry learning. Recommended for beginning reading.

Learning in Science (1985)
Roger Osbourne and Peter Freyberg
Heinemann
ISBN# 0-86863-275-9

This book explores the way children learn and provides discussions about teaching science through constructivist strategies. Sections of particular interest include "Building on Children's Intuitive Ideas," "Facing Mismatches in the Classroom," and "The Role of the Teacher." Readings apply for upper elementary and middle school students.

Organizing Wonder: Making Inquiry Science Work in the Elementary School (1998)
Jody Hall, with Carol Callahan, Helen Kitchel, Patricia Pierce, and Pedie O' Brien
Heinemann
ISBN# 0-325-00045-X

Hall, in collaboration with the other authors/teachers, presents seven steps in encouraging students to engage in science through inquiry investigations. The authors highlight the importance of providing students with explorations that generate student-initiated questions. Each of the four collaborating authors provides classroom vignettes that describe students conducting scientific investigations. The foreword was written by Dr. Wynne Harlen, internationally renowned for her work and research in inquiry-based learning. Highly recommended.

Beyond the Science Kit: Inquiry in Action (1996)
Edited by Wendy Saul and Jeanne Reardon
Heinemann
ISBN# 0-435-07102-5

Saul and Reardon, in collaboration with other authors/teachers, present essays that show teachers how to use science kits as starting points for engaging students in inquiry investigations. Each of the collaborating authors provides classroom case studies and vignettes that describe how inquiry happens in the classroom. One essay provides an alternative to the typical science fair: "A Kids' Inquiry Conference." Recommended.

Nurturing Inquiry: Real Science for the Elementary Classroom (1999)
Charles Pierce
Heinemann
ISBN# 0-325-00135-9

This book looks into one teacher's classroom and shows how inquiry is sustained throughout the entire school year. The author is a classroom teacher and a recipient of the President's Award for Excellence in Teaching Science. Part 1 introduces the reader to how Pierce prepares his room, the student, and himself for an inquiry-based unit of study. Part 2 explains how the "fire" is sustained through the year, and Part 3 provides assessment strategies that complement inquiry instruction. The foreword is written by Wendy Saul, editor of Organizing Wonder *and other books in inquiry.*

Inquiry at the Window: Pursuing the Wonder of Learners (1997)
Phyllis Whitin and David Whitin
Heinemann
ISBN# 0-435-07131-9

Some may think that inquiry is confined to a particular unit of study or for a particular period of the school year. In this book, teacher Phyllis Whitin shows the reader how an event as simple as observing birds outside a classroom window led to an ongoing investigation about behavior and eating habits. As the students conduct their investigations, the author paints a picture of how important making observations and recording data are to any inquiry investigation. The reader is left with the sense of wonder that is manifested through inquiry. The study shows how one science inquiry can lead to an interdisciplinary focus. Highly recommended.

The Learning Cycle: Elementary School Science and Beyond (1997)
Edmund Marek and Ann Cavallo
Heinemann
ISBN# 0-435-07133-5

One of the best ways to start off in inquiry is to use the Learning Cycle approach to lesson development, and one of the best ways to learn about the Learning Cycle is with this book. The authors provide a theoretical framework that includes references to the work of Piaget, Ausubel, and Vygotsky. Whether you use the 3- or 5-E format, the Learning Cycle includes strategies for integrating constructivism and inquiry into your science lessons. The book also includes sample science lessons for elementary classrooms that could easily be extended in the middle level grades. Highly recommended.

Talking Their Way Into Science (1995)
Karen Gallas
Teachers College Press
ISBN# 0-8077-3435-7

For primary-level teachers, giving students the opportunity to discuss and share their understanding provides a startling insight into what students hold as theory about science. Gallas believes that discourse is an essential means for developing concepts for first and second graders. This books offers practical aspects of how children learn through *inquiry and constructivist principles and how to use children's questions as points of departure for science lessons. The chapter on the teacher as a model and a coach is of special interest. Highly recommended for early childhood teachers.*

Constructivism: Theory, Perspectives, and Practice (1996)
Edited by Catherine Twomey Fosnot
Teachers College Press
ISBN# 0-8077-3489-8

The chapters in this book provide the reader with applications of constructivism in mathematics, science, art, and language arts. For science teachers, the three introductory chapters by von Glasersfeld, Fosnot, and Cobb offer an introduction into constructivism's theoretical foundation.

Improving Teaching and Learning in Science and Mathematics (1996)
Edited by David Treagust, Reinders Duit, and Barry Fraser
Teachers College Press
ISBN# 0-8077-3479-9

From a series of internationally renowned authors, this book offers a theoretical background for understanding constructivist principles in science and mathematics. Of particular interest for science teachers is the introductory chapter that provides an overview of students' preconceptions—a starting point for planning science instruction. The chapter on concept mapping by Novak deals with organizing student understanding into hierarchical schematic structures. The chapter by Duit and Confrey offers a rethinking of the aim of science and math instruction and suggests ways to implement a new course of action.

Enquiring Teachers, Enquiring Learners: A Constructivist Approach for Teaching (1989)
Catherine Twomey Fosnot
Teachers College Press
ISBN# 0-8077-2979-5

Using the analogy of a plant starting from seed, Fosnot takes the reader through a generation of research that grows into an alternative to the traditional approach of staff development. She proposes that teachers engage as learners and researchers in education. In the foreword, Eleanor Duckworth says "Fosnot makes it clear in this volume, we teach as we have been taught." This book, although not specific to science, provides applications to language development and mathematics.

Issues in Science Education (1996)
Edited by Jack Rhoton and Patricia Bowers
National Science Education Leadership Association/National Science Teachers Association
ISBN# 0-87355-135-0

Although not specifically about inquiry, this book offers the reader useful background material regarding the changing tide of educational reform. Chapters include issues in science research and reform, technology integration, assessment procedures, leadership, effecting change, and professional development. A chapter on "The Constructivist Leader," provides an application of constructivism to all science leaders, administrators, and supervisors. Recommended.

Achieving Scientific Literacy (1997)
Rodger Bybee
Heinemann
ISBN# 0-435-07134-3

Teachers becoming proficient in inquiry should also establish themselves as knowledgeable agents in the area of scientific literacy and educational reform. One way to become more knowledgeable on these issues is to start with this book. Bybee offers a vision for improving science instruction, focusing on achieving scientific literacy using a standards-based approach. Topics include defining scientific literacy, establishing national standards, and creating a vision for the future. Recommended.

Using the Learning Cycle to Teach Physical Science: A Hands-On Approach for the Middle Grades (1996)
Paul Beinherz and Marylou Dantonio
Heinemann
ISBN# 0-435-08376-7

After a brief description of the learning cycle, the authors provide sample lessons on seven physical science topics ranging from Bernoulli's principle to surface tension.

Targeting Student's Science Misconceptions: Physical Science Activities Using the Conceptual Change Model (1994)
Joseph Stepans
Idea Factory
ISBN# 1-885041-00-4

The book begins with a brief discussion on misconceptions and conceptual change, followed by sample lessons on 15 physical science topics ranging from matter to light and color.

Critical and Creative Thinking: Strategies for Classroom Inquiry (1995)
Susan Wilks
Heinemann
ISBN# 0-435-08869-6

Inquiry-based classrooms are often predicated on open discussions, student participation, and questions to investigate. Wilks provides the reader with some of the techniques and strategies to bring about a "community of learners" within an inquiry environment. Although not specific to science, the author shows how critical and creative thinking are essential in elementary inquiry classrooms. Topics include the role of inquiry, encouraging pupil participation, and several case studies.

The Science of Problem Solving: A Practical Guide for Science Teachers (1991)
Mike Watts
Heinemann
ISBN# 0-304-31985-6

In Chapter 1, Watts provides the reader with an overview of problem solving. In Chapter 2, the skills, process, and methods of problem solving are shared. Other topics include implications of constructivism, cooperative learning, and classroom management.

Science for All Children: A Guide to Improving Elementary Science Education in Your School District (1997)
National Science Resource Center
National Academy Press
ISBN# 0-309-05297-1

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This book offers a recipe for science education reform. In Part 1, a vision for developing an exemplary elementary science program is discussed with reference to the latest research on how children learn science. In Part 2, specific references to inquiry include selection of instructional materials, professional development, assessments, and building support. Part 3 includes case studies of eight school districts implementing the recommendations of the National Science Resource Center. Recommended.

Active Assessment for Active Science: A Guide for Elementary School Teachers (1994)
George Hein and Sabra Price
Heinemann
ISBN# 0-435-08361-9

This is a clear and straightforward approach to designing alternative, authentic, or performance assessments. In Chapter 1, the authors build a case for active assessment by describing the growing trend in science education. Forms of assessment used to evaluate student progress are discussed: tests ("pre" and "post), questionnaires, concept maps, embedded activities, self-evaluations, and portfolios. Chapter 3 provides some realistic and practical suggestions for those just getting started, as well as tips for managing the transition from traditional to alternative assessment procedures. Other chapters on interpreting children's work and using rubrics will be useful to the reader. Highly recommended.

Constructivism in Education (1995)
Edited by Leslie Steffe and Jerry Gale
Lawrence Erlbaum
ISBN# 0-8058-1096-X

This book is recommended for those with an established understanding of constructivism. The chapters provide extensive background into the research and philosophy of constructivist principles. The introductory chapter by von Glasersfeld is interesting reading.

Science With Reason (1995)
Edited by Sue Atkinson and Marilyn Fleer
Heinemann
ISBN# 0-435-08381-3

The basis for this book stems from the editors' belief that "learning in young children takes place through participation in purposeful activity; and that it needs to give a very high profile to the role of language in conceptual development." The book shares the stories of 16 Australian teachers committed to this goal. Their stories provide the reader with a look into their classrooms.

Theme Immersion: Inquiry-Based Curriculum in Elementary and Middle Schools (1994)
Maryann Manning, Gary Manning, and Roberta Long
Heinemann
ISBN# 0-435-08806-8

For teachers who have established inquiry-based classrooms and want to take the next step of integrating inquiry with thematic units, this is an excellent resource. According to the authors, theme immersion is an "in-depth study of a topic, issue or question." By combining inquiry and a thematic approach, the authors provide practical suggestions for planning and implementing theme immersion units. Assessment procedures and several examples of units are provided. Recommended.

School/College Partnerships: Inquiry-Based Science and Technology for All Students and Teachers (1998)
Edited by Merle Bruno and Jacqueline Chase
Science and Technology Education Partnership, Hampshire College
The guide can be requested through Hampshire College (Amherst, MA 01002) or accessed from the World Wide Web at: http://demeter.hampshire.edu/7Emanual

This free guide provides suggestions for establishing partnerships in inquiry between schools and universities. Examples are offered for day and residential camps for children.

Meaningful Science: Teachers Doing Inquiry + Teaching Science (1999)
Edited by Terrie Kieborn and Penny Gilmer
Eisenhower Consortium for Mathematics and Science Education at SERVE (Southeastern Regional Vision of Education)
Available from SERVE, 1203 Governor's Square Blvd., Suite 400, Tallahassee, FL, 32301

This booklet traces the experiences of seven teachers who participated in inquiry-based research projects as part of their doctoral programs. The seven teachers describe their research projects and how they applied their research and skills to their science classrooms.

Tools of the Mind: The Vygotskian Approach to Early Childhood Education (1996)
Elena Bodrova and Deborah Leong
Merrill/Prentice Hall
ISBN# 0-02-369874-8

Enabling teachers "to arm young children with the mental tools necessary for learning" is the essential purpose of this book. Using a Vygotskian approach as a philosophical foundation, the authors show how early childhood students acquire the mental tools for learning. In Section 2, the general strategies for using Vygotsky's Zone of Proximal Development introduce the reader to scaffolding techniques. Recommended.

The Practice of Constructivism in Science Education (1993)
Edited by Kenneth Tobin
Lawrence Erlbaum
ISBN# 0-8085-1878-2

This is one of the most quoted sources on the topic. Part 1 describes the nature of constructivism, including observations by authors Tobin and von Glasersfeld. Part 2 identifies teaching and learning in science and mathematics, and Part 3 provides the perspective of teachers learning to change. The book is recommended for those who have a basic understanding of constructivism. It is an excellent resource but probably shouldn't be the first book you read on constructivism. Highly recommended.

Teaching and Learning Primary Science, Second Edition (1993)
Wynne Harlen
Paul Chapman
ISBN# 1-85396-185-X

Like all of Harlen's books, this is a useful and practical guide for elementary teachers. With a research-based approach, Harlen takes the reader through the development of how children learn science and the ideas they bring to our classrooms. In this edition, the role of language and process skills are addressed in relation to how they facilitate children's thinking in science. Additional topics include the role of the teacher and assessment strategies. This book is an excellent follow-up to Harlen's Taking the Plunge. *Highly recommended.*

Multimedia Resources

Creating the Active Classroom (1994) (Videodisc)
Decision Development Corporation

Whether you are looking for professional development or college course resources, this interactive videodisc program will certainly meet your teaching needs. Following a constructivist approach to staff development, this program follows the lessons of five science teachers. It includes effective strategies for ESL/LEP instruction. Individual segments are bar coded for easy access. Included workshop guide. Highly recommended.

Constructivism (1995) (Videotape)
Association for Supervision and Curriculum Development
1250 North Pitt Street, Alexandria, VA, 22314

A two-part video program complements Brooks and Brooks's In Search of Understanding: The Case for Constructivist Classrooms. *Part 1 highlights the book's five guiding principles of constructivism: (a) posing problems of emerging relevance to students, (b) structuring learning about primary concepts, (c) seeking and valuing students' points of view, (d) adapting curriculum to address students' suppositions, and (e) assessing student learning in the context of teaching. Part 2 includes case studies for various constructivist classrooms. A facilitator's guide includes a suggested workshop format, overheads, and handout materials. Highly recommended for professional development or college education courses.*

The Private Universe (1987) (Videotape)
Produced by Matthew Schneps and the Science Media Group of the Harvard-Smithsonian Center for Astrophysics
Distributed by Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112
Order online at: http://www.learner.org/collections/mathsci/teachers/pup/

According to Annenberg, "From its famous opening scene at a Harvard graduation, this classic of educational research brings into sharp focus the dilemma facing all educators: Why don't even the brightest students truly grasp basic science concepts?" This award-winning program traces the problem through interviews with eloquent Harvard graduates and professors and Heather, a bright middle school student who has some strange ideas about the orbits of the planets. Equally fitting for education methods classes, teacher workshops, and presentations to the public, it is an essential resource for any educational video collection. Highly Recommended.

Internet Resources

http://www.exploratorium.com/IFI/index.html

According to the Exploratorium, the Institute for Inquiry was "created in response to widespread interest in inquiry-based science instruction. The Exploratorium Institute for Inquiry provides workshops, programs, on-line support, and an intellectual community of practice that afford science reform educators a deep and rich experience of how inquiry learning looks and feels."

http://www.scienceinquiry.com/index.htm (Tik Liem's Web site)

According to this Web site, "Science Inquiry Enterprises offers teaching resources for science educators as well as parents of homeschoolers and those who have an interest in sci-

ence. These materials offer a unique approach to the teaching of science through the use of discrepant-event demonstrations and activities. These are demonstrations that have very unexpected results, causing those observing to ask questions that will eventually lead them to the understanding of the science concepts being presented. These teaching resources have been widely used around the world and endorsed by teachers and parents alike."

http://www.nwrel.org/msec/pub.html
Inquiry Strategies for Science and Mathematics Learning: It's Just Good Teaching

According to NWREL (Northwest Regional Educational Laboratory), this document "provides the rationale for using inquiry-based teaching and offers specific strategies that teachers can use in the classroom to facilitate their students' learning of concepts and skills. Based on research and including interviews with Northwest teachers, the publication addresses issues such as new roles for students and teachers, choosing and presenting an inquiry topic, classroom discourse and questioning, and ensuring attention to content as well as process. A list of resources, including print materials, on-line sources, and organizations, enables teachers to explore additional tools to support their efforts in creating an inquiry-based classroom." Highly recommended.

www.concord.org
Concord Consortium

Ideas and resources for teaching inquiry.

www.learner.org
Annenberg/CPB

Premiere Web site for professional development resources and videos in science and mathematics. Web site lists include schedules of distance-learning video series. Programs include: Teaching High School Science (Grades 9-12); Science Firsthand (Grades 7-9); Case Studies in Science Education (K-8); Science K-6: Investigating Classrooms; The Science of Teaching Science: For K-8 Science Education; Minds of Our Own (elementary and middle level); and Private Universe Teacher Workshops (Grades K-12).

www.pbs.org/teachersource/scienceline
PBS TeacherSource: Scienceline

Videos of elementary teachers in a variety of school settings focus on standards-based and inquiry-based science instruction.

For other Web sites and Web pages on inquiry-based instruction, use a search engine for "inquiry," "science," "teaching," "inquiry-based teaching," "constructivism," or "learner-centered instruction."

Happy Web surfing!

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Resource B

Inquiry Self-Assessment Response Grids

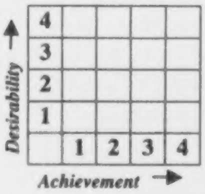
1. Curriculum

1.1

1.2

1.3

1.4

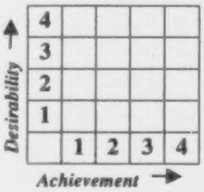


1.5

1.6

1.7

1.8



2. Lesson Presentation

2.1

2.2

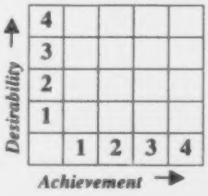
2.3

2.4

2.5

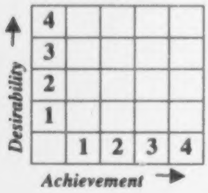
2.6

2.7



3. Communication

3.1



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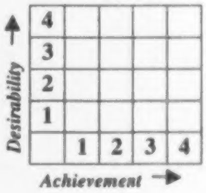

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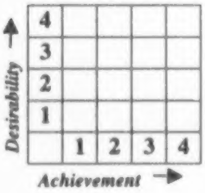

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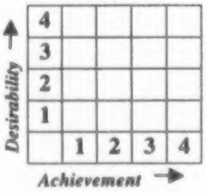

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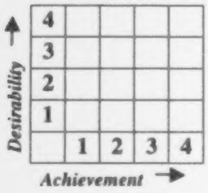
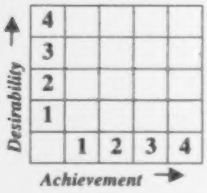


4. Engagement of Students

4.1



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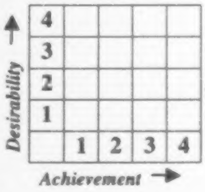

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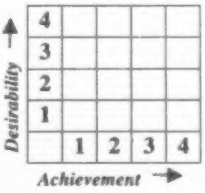

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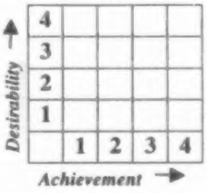

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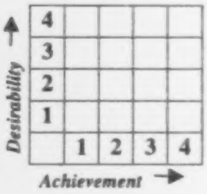

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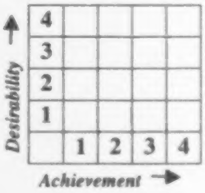


5. Classroom Organization

5.1

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

5.2

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

5.3

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

5.4

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

5.5

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

5.6

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

5.7

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

6. Questioning Skills

6.1

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

6.2

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

6.3

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

6.4

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

6.5

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

6.6

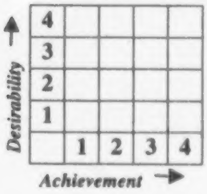
Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

7. Assessment Procedures

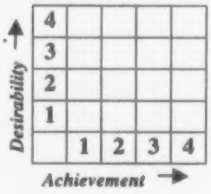
7.1



7.2

7.3

7.4

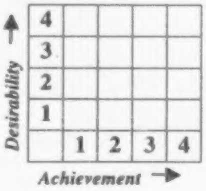


7.5

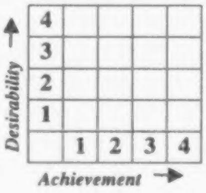
8. Professional Development

8.1

8.2



8.3



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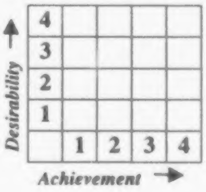


8.5

Resource C

Inquiry Self-Assessment Summary Matrix

1. Communication

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

2. Lesson Presentation

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

3. Communication

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

4. Engagement of Students

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

5. Classroom Organization

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

6. Questioning Skills

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

7. Assessment Procedures

Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

8. Professional Development

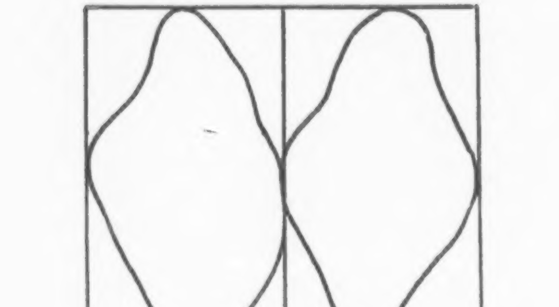
Desirability ↑

4				
3				
2				
1				
	1	2	3	4

Achievement →

Resource D

Diagrams for Short-Eared and Long-Eared Bugs-o-Copters



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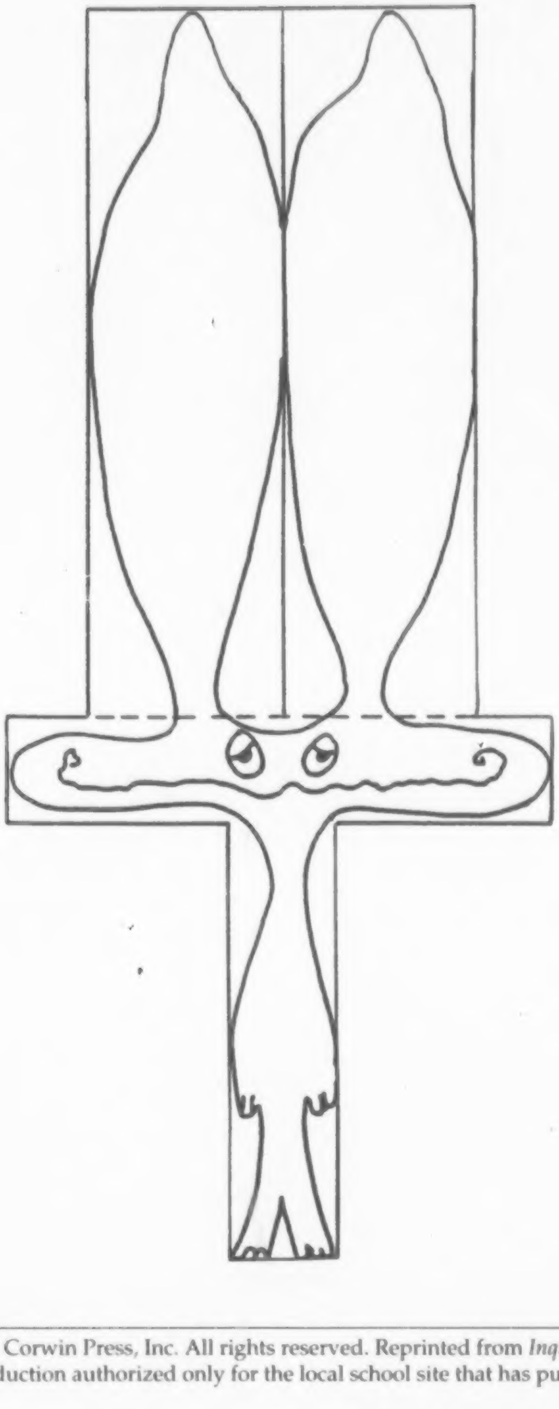

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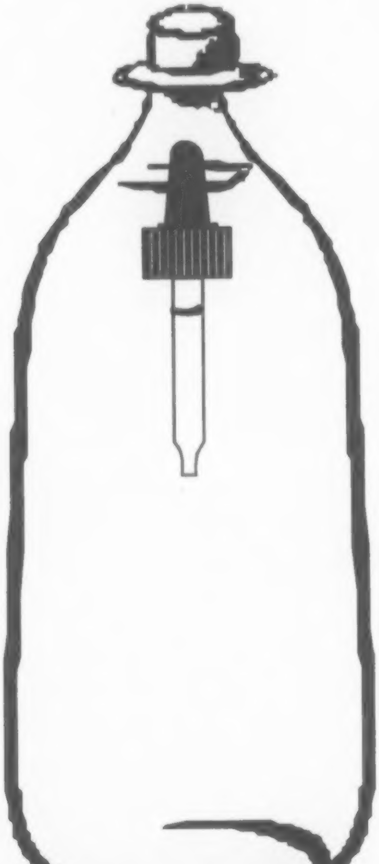
Resource E

How to Make a Cartesian Diver

1. Remove the screw top, label, and base from a clear plastic 2-liter soda container.
2. Fill the 2-liter container with water and set it aside.
3. Fill a separate large glass (about 6-8 inches tall) with water.
4. Fill an eyedropper with enough water (about half full) so the dropper just floats when placed in the glass of water. The rubber top of the eyedropper should just break the surface of the water.
5. Remove the eyedropper from the glass and place it in the 2-liter container.
6. Replace the screw top back on the container.
7. Gently squeeze the sides of the container and observe what happens to the eyedropper (diver).



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Author Index

Abraham, M., 91
Adams, D., 57
American Association for the Advancement of Science, viii, 3, 6, 7, 8, 9, 10, 57
Aschbacher, P., 99
Atkin, J. M., 91
Ausubel, D., x, 29, 44

Barman, C. R., 91
Beisenherz, P., 91
Bell, B., 8
Biological Sciences Curriculum Study, 9
Brooks, J., 58
Brooks, M., 58
Bybee, R., 91

Campbell, P., 81, 82
Cavallo, A., 91
Clough, M., 91
Colburn, A., 76, 91

Dantonio, M., 91
DeBoer, G., 42
Dewey, J., x, 9, 29, 44
Driscoll, M., 41, 43
Duit, R., 33

Edwards, C., 63
Exploratorium, x, 3, 5, 16

Froschl, M., 81, 82

Gagne, R., 86
Gallwey, W. T., 107-108
Gerlovich, J., 91
Gertzog, W., 32
Gilbert, J., 8
Gowin, D., 1

Hamm, M., 57
Hart, D., 98
Haury, D., 10
Hein, G., 98, 101
Herman, J., 99
Hester, J., 10, 86
Hewson, P., 32
Holubec E. J., 82
Howe, A., 38
Hunkins, F., 10, 85

Johnson, D., 82
Johnson, R. T., 82
Jones, L., 38

Karplus, R., 39, 91
Kotar, M., 91

Lawson, A., 91
Liem, T., 91

Llewellyn, D., 64, 65, 69
Lorsbach, A., 30

Macrina, F., 79
Marek, E., 91
Martin, R., 91
Moore, K., 134

National Center for Improving Science Education, 99
National Research Council, viii, xi, 3, 6, 7, 10, 56, 85, 98, 125 (table note)
National Science Teachers Association, viii, 110
Novak, J., 1, 44

Olge, D., 39

Phillips, D. C., 33, 41, 42
Piaget, J., x, 29, 43, 44
Posner, G., 32
Price, S., 98, 102

Renner, J., 91
Rowe, M. B., 131

Sergiovanni, T., 118
Sexton, C., 91
Shiland, T. W., 76
Soltis, J., 33, 41, 42
Sprung, B., 81, 82
Strike, K., 32

Thier, H., 39, 91
Thorndike, E., 40
Tobin, K., 30
Treagust, D., 33

Watson, J., 80
Watts, M., 89
Winters, L., 99
Wolfe, P., 34

Yager, R., viii

Subject Index

Activities, 64
  and inviting inquiry, 67-68
  in lessons, 66-67
  marble, 72-74, 80-81
  modifying into inquiry, 76-78
  problem solving, 86-87
  worksheets, 28 (form), 73 (form)
  See also Demonstrations
Activities, teacher-directed, 67
American Association for the Advancement of Science (AAAS), 6-7
Assessments, 99
  and misconceptions, 9
  and rubrics, 109-110, 120-125 (table)
  and surveys, 110-115, 111-112 (figure), 114-115 (figure)
  vs. evaluation, 98-99
Ausubel, David, 44

Behavior in classroom, 54-56, 57-58
  of teachers, 59-60
Behavior, research in learning, 40-41
Behaviorism, 30
  background of, 40-41
Beliefs:
  and disequilibrium, 44
  and equilibrium, 43
  changing, 31, 32
  Conceptual change model, 31
  of young children, 31, 38, 49
  See also Concepts; Misconceptions

Children. *See* Students; Students, secondary; Students, younger
Classroom environment and teachers, 8
Classrooms, constructivist, 46
Classrooms, inquiry-centered, 60-61, 138-139, 142
  designing, 54
  student behavior in, 54-56
  teacher behavior in, 59-60
Classrooms, traditional, 53
Cognitive development, 42-44, 49
Commitment, 109
Concept maps, 1-3, 2 (figure), 101, 103 (figure)
  in lesson, 18 (figure), 26 (figure)
Concepts:
  and learning cycle, 93
  changing, 32
  See also Misconceptions
Conceptual change model, 31
Constructivism:
  and classrooms, 46
  and conceptual change model, 31
  background of, 42-44
  definition of, 29-30
  development of, 39-44
  inquiry cycle, 47 (figure)
  key points of, 44-45

Demonstrations, 65
  and discrepant events, 65-66
  marble, 70-72
  reasons for, 65
  See also Activities
Dewey, John, 42
Discovery process, 10-11
Discrepant events in lessons, 65-66, 91
  "Happy and Unhappy Balls," 66

Elaboration stage, 97-98
Engagement stage, 94-95
Evaluation stage, 98-99
Evaluations vs. assessments, 98-99
Explanation stage, 97
Exploration stage, 95
Exploratorium, 5-6
Exploratorium Institute for Inquiry, 3-5
Extension stage, 97-98

Forms:
  activity worksheets, 73
  concept maps, 2 (figure), 103 (figure)
  inquiry data sheets, 96
  monitoring charts, 102 (figure)
  self-assessment surveys, 111-112 (figure), 114-115 (figure)
  self-evaluation, 28, 104

Groups, working in, 57-58

Hands-on science:
  as learning tool, 43, 72
  as misconception, 7-8
  vs. inquiry-based investigations, 70
Hypothesis, 79, 80, 117

Inquiry, 62 (figure), 71 (figure)
  and assessment procedures, 99
  and concept maps, 1-3, 5
  and content, 9-10
  and equal opportunity learning, 10
  background of, 9
  benefits of, 140, 144
  for teachers, 116-118
  four stages of instruction, 64, 64 (figure), 70-75, 77 (figure)
  introducing in lessons, 64, 69-70, 76-78, 92-93
  misconceptions of, 7-10
  procedures for, 80-85
  promoting, 63-64
  vs. problem solving, 86-87
  See also Lessons, examples of inquiry-based; Lessons, inquiry based
Inquiry cycle, 15 (figure)
  as general format, 16
  constructavist, 47 (figure)
  in lesson, 13-16, 47 (figure)
Inquiry, definitions of, 1, 16, 142
  American Association for the Advancement of Science (AAAS), 6-7
  Exploratorium, 5-6
  Exploratorium Institute for Inquiry, 3-5
  National Research Council (NRC), 6
Inquiry standards and grade levels, 6, 7
Inquiry, student-initiated, 64, 69, 70 (figure), 74, 93
Inquiry, teacher-initiated, 64, 68-69, 70 (figure), 74
Interpretation. *See* Concepts; Misconceptions

Learning cycle, 91-93, 142
  and assessments, 99
  and concept maps, 101, 103 (figure)
  and monitoring charts, 101, 102 (figure)
  and portfolios, 99-100
  and rubrics, 100
  and self-evaluations, 101, 104 (form)
  lesson following, 93-106
  model of, 39, 91, 92 (figure)
Learning model, constructivist, 30-31
Learning process, 50, 51
  and behavior, 55-56
  See also Cognitive development; Learning cycle
Learning skills, 51
Lectures, 8-9
Lessons, examples of inquiry-based:
  "Bugs-o-Copters," 116-118
  earth and moon, 36-38
  "Exploring Momentum With Ramps and Balls," 82-85
  fruit, 11-16
  ice, 17-27, 45-46
  marble, 74, 80-81
  "Mealworms to Go," 93-106
  "Pumpkin Math & Science," 68-69
  See also Activities; Demonstrations; Forms; Lessons, inquiry-based
Lessons, inquiry-based, 139, 143

  - activities in, 66-68
  - and learning cycle, 91-93
  - demonstrations in, 65
  - discrepant events in, 65-66, 91
  - first attempts at, 108-109
  - introducing inquiry in, 64, 69-70, 76-78
  - procedures for, 80-85
  - summary of, 103-106
  - *See also* Lessons, examples of inquiry-based
- Locke, John, 40

- Misconceptions:
  - as preconcevied notions, 32-33
  - of inquiry, 7-10
  - revealing, 38-39, 92
  - sources of, 34-36
  - teaching to, 38
  - *See also* Concepts
- Models, 48, 107-108
- Monitoring charts, 101, 102 (figure)

- National Research Council (NRC), 6

- Paradigm shifts, 49
- Peers:
  - ridicule from, 38, 50
  - working with in groups, 57-58
- Piaget, Jean, 42-44
- Portfolios, 99-100
- Problem solving, 88 (figure)
  - in lesson, 97
  - research in, 42-44
  - scientific, 85-89
  - vs. inquiry, 86-87
- Procedures:
  - assessment, 98-99
  - for inquiry, 80-85
  - for problem solving, 86-89, 88 (figure)
  - learning cycle, 91-93

- Questions, 8, 139-140, 143-144
  - and interaction, 135 (figure), 135-137, 136 (figure)
  - and scientific method, 80
  - and wait time, 131
  - by teachers, 128-130
  - in inquiry exercise, 74-75, 75 (figure), 84-85, 118
  - phrasing of, 128
  - sorting, 129 (figure)
  - types of, 127-128, 134

- Redirectioning, 135-137
- Research by students, 56-57
- Rubrics, 100
  - as assessment tool, 109-110, 120-125 (table)

- Science, interests in, 58-59
  - and discrepant events, 65-66
- Scientific methodology, 46-49, 79-85
  - and misconceptions, 8
  - and theory building, 49
  - and younger children, 82-85
  - steps of, 80
- Self-assessment survey, 110-115, 111-112 (figure), 114-115 (figure)
- Self-doubt, 108-109
- Self-evaluation, 28 (form), 101, 104 (form)
- Skinner, B. F., 41
- Students:
  - and cognitive development, 49-50
  - and conceptual change model, 31
  - and inquiry cycle, 13-16
  - and learning cycle, 39
  - and ridicule, 38, 50
  - and teacher interaction, 135 (figure), 135-137, 136 (figure)
  - and wait time, 131
  - as researchers, 56-57
  - behavior of, 54-56, 57-58
  - diplomas for, 103, 105 (figure)
  - equal opportunity learning for, 10
  - inquiries initiated by, 17-27, 45-46, 69
  - interest in science, 58-59
  - misconceptions of, 32-36, 38
  - questions from, 8, 128
  - working in groups, 57-58
  - *See also* Peers
- Students, secondary:
  - lesson for, 93-106
  - thinking skills of, 58
- Students, younger:
  - inquiry procedure with, 82-85
- Summary of inquiry-based unit, 103-106

- Teachers, 56-57
  - and classroom behavior, 57-58, 59-60
  - and classroom environment, 8
  - and learning inquiry, 116-119, 141, 144-145
  - and modeling, 107-108
  - and monitoring charts, 101
  - and self-doubt, 108-109

  and student interaction, 135 (figure), 135-137, 136 (figure)
  assessment of, 109-115, 111-112 (figure), 114-115 (figure), 120-125 (table)
  commitment of, 109
  Dzinbal, Danielle, 138-141
  Guarino, Lucia Falsetti, 141-145
  questioning by, 128-133
Teaching styles:
  behaviorism, 30
  constructivism, 30, 31
  inquiry-based, 140-141
Theory building, 49
Thinking skills, 10-11
Thorndike, Edward, 40-41
Time constraints, 9

Variables, 80-81, 117

Wait-time, 131

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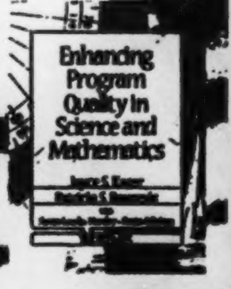

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